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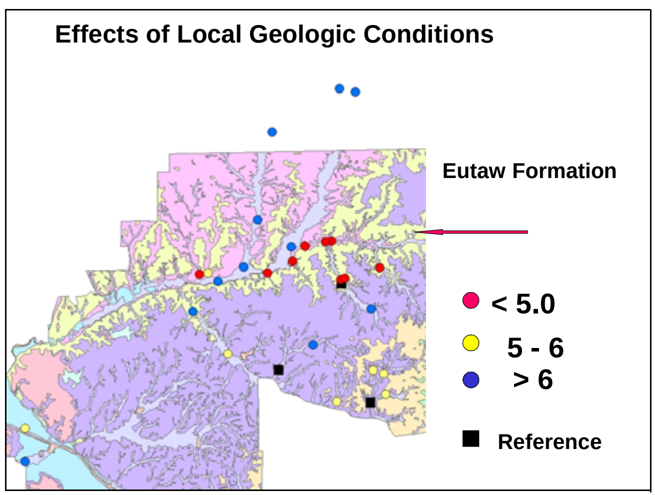
SERDP Ecosystem Management Project (SEMP)

2003 Technical Report

March 2004



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SERDP Ecosystem Management Project (SEMP): 2003 Technical Report

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Final Report

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Prepared for Strategic Environmental Research and Development Program (SERDP)

Under Work Unit 1114#

ABSTRACT: The SERDP Ecosystem Management Project (SEMP) was initiated in 1998 by the Strategic Environmental Research and Development Program (SERDP), after a 1997 workshop on Department of Defense (DoD) ecosystem management challenges. After the workshop, SERDP allocated initial funding to a new project, titled the SERDP Ecosystem Management Project, designated as CS 1114.

This report provides a comprehensive record of the progress and issues related to SEMP up to and during Fiscal Year 2003 (FY03, October 2002 through September 2003). Chapter 2 provides the status and findings of the monitoring effort, while Chapter 3 describes efforts to obtain comparable climatic and land cover data. Chapters 4 through 8 summarize the projects' status and progress during FY03. This document also presents information on the SEMP integration task, site comparison indices, related research efforts, the SEMP data repository, the host site coordinator's report, and technology infusion and transfer.

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Contents

List of Figures and Tables

Figures

Tables

Conversion Factors

Non-SI* units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(5/9) x (°F – 32)	degrees Celsius
degrees Fahrenheit	(5/9) x (°F – 32) + 273.15.	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 Fort-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

***Système International d'Unités* ("International System of Measurement"), commonly known as the "metric system."

Preface

This study was conducted for the Strategic Environmental Research and Development Program (SERDP) Office under SERDP Work Unit CS-1114, "SERDP Ecosystem Management Project (SEMP)." The technical monitor was Robert W. Holst, Program Manager.

The work was performed under the direction of the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The technical editor was Gloria J. Wienke, Information Technology Laboratory. Steven D. Hodapp is Chief, CEERD-CN-N, and Dr. John T. Bandy is Chief, CEERD-CN. The associated Technical Director was Dr. William D. Severinghaus, CEERD-CV-T. The Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan and the Director of ERDC is Dr. James R. Houston.

1 Introduction

1.1 Background

Mr. William D. Goran, ERDC/CERL

The SERDP Ecosystem Management Project (SEMP) was initiated in 1998 by the Strategic Environmental Research and Development Program (SERDP), after a 1997 workshop on Department of Defense (DoD) ecosystem management challenges. This workshop was held because the Department of Defense, and each of the services had issued guidance to military installations to employ scientifically sound and adaptive ecosystem management approaches to manage military owned/used lands, and the services had identified research needs related to this guidance.

Below is an excerpt from an 8 August 1994 memorandum from Sherri Wasserman Goodman, who was then Deputy Undersecretary of Defense for Environmental Security, on ecosystem management:

> I want to ensure that ecosystem management becomes the basis for future management of DoD lands and waters. Ecosystem management is not only a smart way of doing business, it will blend multiple-use needs and provide a consistent framework to managing DoD installations, ensuring the integrity of the system remains intact. Ecosystem management of natural resources draws on a collaboratively developed vision of desired future ecosystem conditions that integrates ecological, economic, and social factors. It is a goal-driven approach to restoring and sustaining healthy ecosystems and their functions and values using the best science available. The goal is to maintain and improve the sustainability and native biological diversity of terrestrial and aquatic, including marine, ecosystems while supporting human needs, including the DoD mission.

The purpose of the 1997 SERDP workshop was to focus, clarify, and prioritize Defense installation ecosystem management research needs related to this guidance. During this workshop, the key themes that emerged included: (1) understanding the status and trend of ecosystems and the role of military use related to status and trends, in relation to the desired conditions identified in the “goal driven approach to restoring and sustaining healthy ecosystems" targeted in the Goodman memorandum, (2) understanding the management "thresholds" for ecosystem conditions, beyond which closer observation and/or mitigating action may be required, (3) understanding the biogeochemical cycles (functions) in the ecosystem, and how military land use and resource management practices impact these cycles, and (4) understanding all of these phenomena at the multiple spatial and temporal scales, from ecoregions to micro-organisms and across days, years, and decades, impacted by military use and management of lands and waterways.

After the workshop, SERDP allocated initial funding to a new project, titled the SERDP Ecosystem Management Project (SEMP), designated as CS 1114, and requested that the Corps of Engineers research laboratories manage this project and establish a planning team. Fort Benning, GA, volunteered to host the research program and the planning team developed an initial research statement of need (SON) for work on the issue of indicators of ecosystem status. Proposals for this statement of need were reviewed in spring 1999, and three research teams (University of Florida, Construction Engineering Research Lab/Prescott College, and Oak Ridge National Lab) were selected to begin multiyear research initiatives against this theme. Chapters 4 through 8 (pages 38 through 140) summarize these projects status and progress during Fiscal Year 2003 (FY03).

In addition, a monitoring program was initiated, in 1999, to establish a long-term set of meteorological, aquatic, and terrestrial conditions for Fort Benning and the surrounding ecoregion. Chapter 2 (page 8) provides the status and findings of this monitoring effort during FY03, while Chapter 3 (page 28) describes efforts to obtain comparable climatic and land cover data for a longer time frame.

Since SEMP field work began in 1999, many new research efforts have been added. Some of these efforts are formally included within SEMP (such as the two threshold projects began in FY00) and many others are leveraging SEMP to explore additional issues at Fort Benning or at other locations along the Sandhills Fall Line area or in the Southeastern Coastal Plain (as described in Chapter 11, page 168). Fort Benning straddles both these ecoregions. Figure 1-1 shows the numerous military installations in this region of the southeastern United States, against green areas that represent ecologically valuable lands in the region. These ecologically valuable lands, which often include military installations, were identified through an analysis conducted by the University of Florida, the Southeastern Region of the Environmental Protection Agency, and other agencies that work together in the Southeastern Natural Resources Leader's Group.

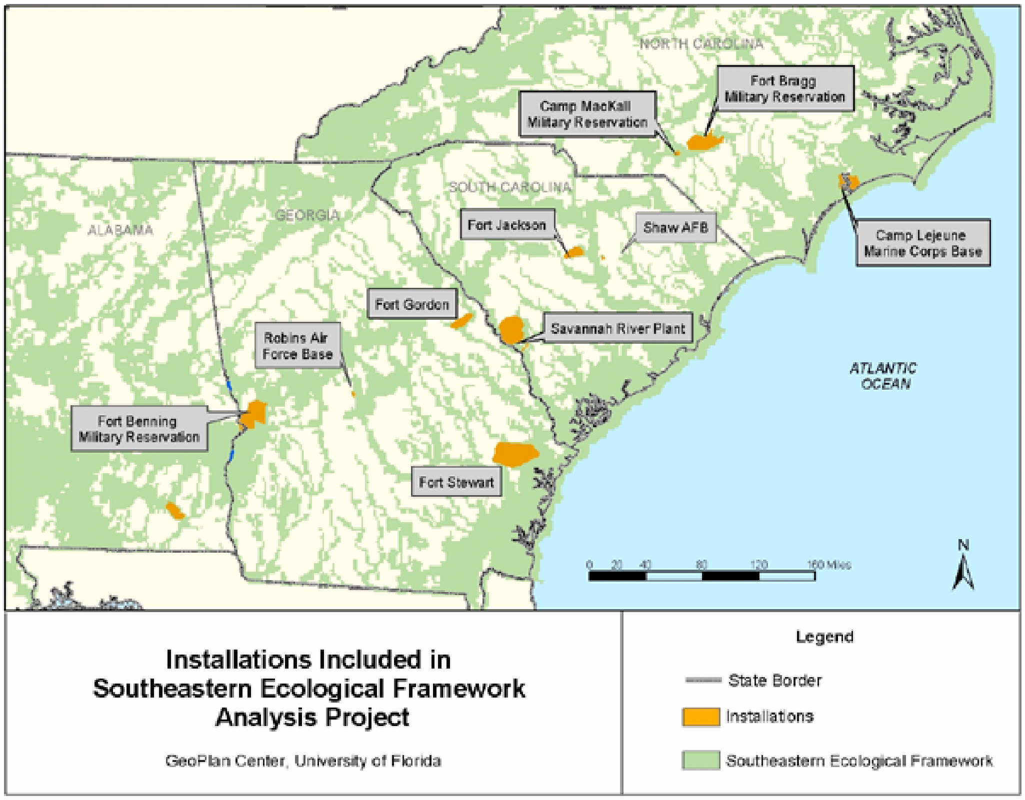

Figure 1-1. Military installations in the Southeast (incuding Fort Benning). Darker green areas are part of the "Ecological Framework" developed by University of Florida and Southeastern Region IV EPA.

Some of these additional projects are sponsored by SERDP, while others are sponsored by Army research programs, leveraged by local universities, or sponsored directly by Fort Benning or other Federal facilities in the region.

1.2 Objectives

The overall objectives established for SEMP are to:

- Address DoD requirements and opportunities in ecosystem management research (1997 SERDP Ecosystem Science Workshop) as identified in the 1997 workshop on ecosystem management research challenges for Department of Defense.
- Establish a long-term research site (or sites) on DoD lands for DoD relevant ecosystems research.
- Conduct additional ecosystem research and monitoring activities relevant to DoD requirements and emerging opportunities.

- Develop ecosystem management tools and practices for and transition to DoD land managers.

SEMP is organized to pursue each of these objectives.

The objective of this report is to provide a comprehensive record of the progress and issues related to SEMP up to and during Fiscal Year 2003 (October 2002 through September 2003). Previous reports covered fiscal year progress for previous years, including the following:

- Unpublished report: Plans and Progress of the Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Project (SEMP), April 2000.
- ERDC SR-01-3: Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Project (SEMP) FY00 Annual Report, September 2001.
- ERDC SR-02-2: Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Project (SEMP) FY01 Annual Report, March 2002.
- Unpublished report: Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Research Project (SEMP) FY02 Annual Report, March 2003.

This report includes all phases and projects directly related to SEMP, including the monitoring efforts, the five research projects that are formally managed as part of SEMP (identified as CS1114A through CS1114E in Chapters 4 through 8, pages 38 through 140). A companion document (*SERDP Ecosystem Management Project (SEMP) 2003 Administrative Report, ERDC SR-04-4*) discusses the various SEMP management, coordination, and technical oversight activities.

The numerous projects that leverage SEMP each develop their own reports, and there is no attempt, within this report, to provide a comprehensive account of their progress.

1.3 Approach

The overall approach for SEMP is pictured in Figure 1-2. This figure, presented to the SERDP Scientific Advisory Board in March 2003, depicts the "flow" of activities for SEMP, moving from the identification of research themes through the competitive solicitation of proposals against each of these themes; the progression of the research; the publication, testing, and validation of outcomes; and transition to the host installations and to other sites beyond the host. The project as a whole is managed by the Engineer Research Development Center (ERDC) of the U.S. Army Corps of Engineers. ERDC provides a Project Manager who is assisted by a Research Coordinator, a Monitoring Team Coordinator, a Repository Coordinator, a Host Site Coordinator, a Technology Transfer Coordinator, and a Reporting Coordinator.

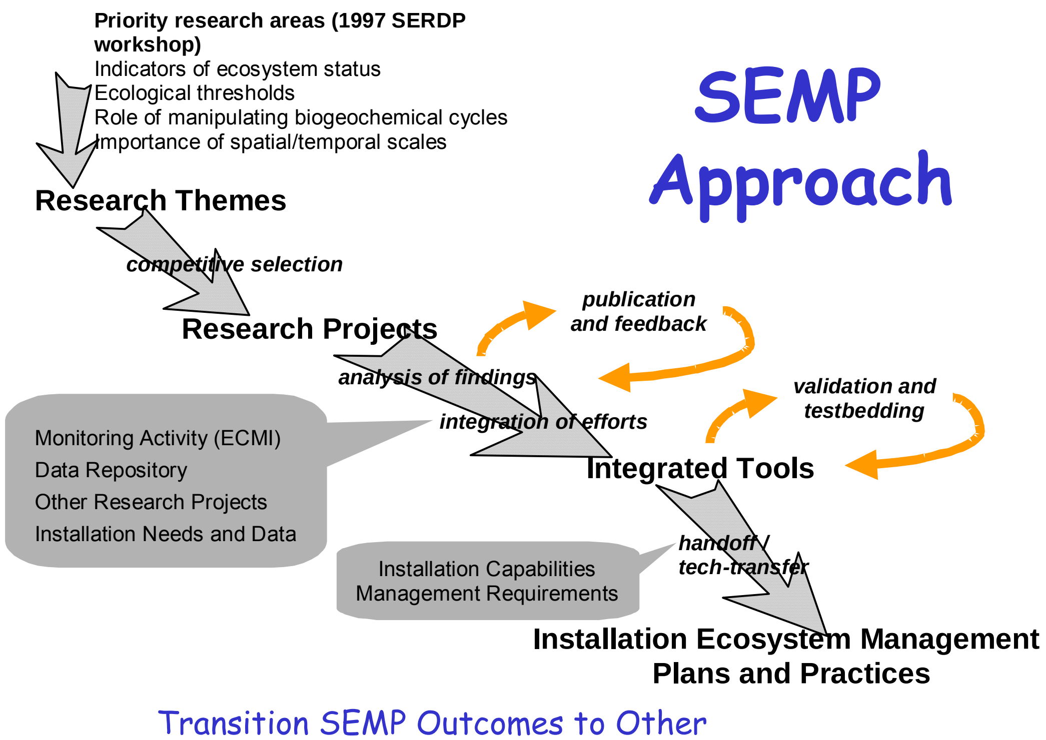

Figure 1-2. The SEMP Approach.

As SEMP is a SERDP project, proposal solicitation, evaluation, and selection practices follow the SERDP approach (posted on the SERDP website at http://www.serdp.org). Once a solicitation is posted on the SERDP website, teams from government, industry, and/or academia draft proposals to address the solicitation. These proposals are reviewed for relevance, and those that are found sufficiently relevant to the solicitation are sent out for a peer review process.

For SEMP solicitations, proposals that emerge successfully (recommended for funding) from the peer review are then reviewed by the SEMP Technical Advisory Committee (TAC) and by the host installation(s). This SEMP TAC group, which first started functioning in 1999, was established to provide oversight, guidance, and coordination for the SEMP projects. Finally, any proposal(s) that is recommended for funding by the SEMP TAC is forwarded to the SERDP Executive Director, to concur or non-concur with the recommendation. Before a new effort is funded, it is also briefed to the SERDP Scientific Advisory Board (SAB), which is a congressionally mandated scientific oversight board for all of SERDP.

After successful review and authorization to proceed, research investigators begin their work, as per their proposed plans. Besides pursuing their research objectives, SEMP investigators collaborate across teams, and there are numerous means to facilitate this collaboration. Annual Research Coordination meetings have been held since 1999. All data from research and monitoring is placed in a central repository (described in Chapter 12, page 173). Teams brief their progress once or twice each year to the SEMP TAC and are encouraged to make presentations at the annual SERDP Symposium, and often at other scientific forums, such as the Ecological Society of America, the American Society of Agronomy, and the North American Wildlife Society.

In 2002, the TAC recommended that a research integration effort be designed. This effort is now underway, with the integration plans and progress reported in Chapter 9 (page 150). This project is designed to identify, screen, and verify proposed indicators of ecological status emerging from across the research teams related to a common installation landscape framework.

The SEMP Research Integration Project will develop candidate indicators of ecological status. These indicators will be screened and tested, through a series of steps, before they are transitioned to installation use. In addition, there are two complimentary approaches to help transition promising outcomes (indicators, thresholds, and other potential outcomes) from SEMP (and related efforts). These include the Sandhills Fall Line initiative, which was presented to the SEMP TAC in 2001, then approved in 2002 for inclusion in the 2003-2006 SEMP budgets (the annual budget is developed by the SEMP Project Manager, then presented for approval to the SEMP TAC, the SERDP Program Office and finally the SERDP SAB).

The Fall Line Sandhills initiative is intended to provide opportunities to test and validate the "transportability" of SEMP research outcomes at multiple locations along this ecoregion. This initiative was delayed until 2004 after a Terrestrial Site Comparison Index was developed and tested.

Another path for testing and validation of promising indicator outcomes is to transition these, temporarily, into the SEMP long-term monitoring effort. Such transitions are also scheduled to begin in 2004.

Finally, all promising outcomes from research, and also from the monitoring effort, as well as new data, analysis tools, identification keys, and other relevant capabilities emerging from SEMP are planned for infusion to installation operations, at the host location(s), and at all other relevant and interested sites in the Southeastern United States and beyond. All such transitions are, of course, guided and constrained by the relevance of these research and monitoring outcomes to military installation ecosystem management goals and objectives. The path for these transitions is described in Chapter 14 (page 187).

1.4 Mode of Technology Transfer

This report will be made accessible through the World Wide Web (WWW) at URL:

http://www.cecer.army.mil

As mentioned, the methodology and plans for SEMP technology transfer are provided in Chapter 14, Technology Infusion and Transfer (page 187).

SEMP also aggressively uses many different means to ensure that information about SEMP and outcomes from SEMP are available to all potentially interested parties. The SEMP website is at http://www.cecer.army.mil/KD/SEMP. This site is referenced from the SERDP site and from the Defense Environmental Network for Information Exchange (DENIX) http://www.denix.osd.mil.

Besides this website, SEMP has a periodic newsletter (*SEMP Postings*) and is developing a short video (*The SEMP Story*). In addition, there have been dozens of presentations about the plans for and progress of SEMP to numerous military and Federal forums, and also to scientific meetings.

In 2001, SEMP sponsored the "Partners Along the Fall Line: Sandhills Ecology and Ecosystem Management Workshop," which was hosted by the Savannah River Ecology Laboratory and attended by several dozen military installation land managers and other Federal and State agency representatives. Proceedings of the workshop are documented in ERDC/CERL Special Report SR-02-2, *Proceedings of the "Partners Along the Fall Line: Sandhills Ecology and Ecosystem Management Workshop*," published in March 2002. A second Fall Line Partnership meeting is planned for spring 2005.

One of the primary modes of technology transfer is publications and presentations. A complete listing of these presentations and various types of publications is provided in Appendix A (page 193).

2 Ecosystem Characterization and Monitoring (ECMI)

Dr. David L. Price, ERDC, Environmental Laboratory, Vicksburg, MS.

2.1 Introduction

2.1.1 Brief Background on Project

Within the SEMP, the Ecosystem Characterization and Monitoring Initiative (ECMI) was established to design, develop, and demonstrate an ecosystem characterization and monitoring concept appropriate for military installations. The ECMI products must support multiple SEMP objectives and be beneficial to installation land managers. The ECMI baseline monitoring concepts are intended to have broad applicability and may serve as a model for other installations.

2.1.2 Objective of Project

The objective of ECMI is to develop a framework to characterize the long-term spatial and temporal dynamics of key ecosystem properties and processes in a way that is jointly beneficial to ecosystem research activities and military land management operations. The monitoring conducted under the ECMI is expected to produce a multi-purpose, integrated, baseline ecological information base. This ECMI information base will:

1. support SEMP ecological research related to sustainable management of DOD lands,
2. contribute baseline level data to the integrated monitoring plan of the host site,
3. establish a long-term ecological data set at the host site that will, over time, allow the assessment of relationships between land use, management and ecosystem sustainability, and
4. be compatible with monitoring data sets collected by other agencies in the region.

2.1.3 Approach

The approach has been to complete the design and implementation phase (Phase I, 1999-2001) as described in "Long-Term Monitoring Program, Fort Benning, GA".[1]. Some adjustments have been made to the original design, in particular to the surface water component because of the extended drought being experience in the Fort Benning region. The ECMI product has now entered the modification phase (Phase II, 2002-2005).

2.2 Summary of Monitoring Activities for FY03

2.2.1 Meteorology, Surface Water, and Ground Water

Meteorology parameters have been monitored at 10 sites since FY99. The data and summary statistics from July 1999 through November 2003 are on the SEMP data repository. The ECMI team continues to work with personnel in both the Land Management Branch and the Battle Lab at Fort Benning to transition the meteorology monitoring from ECMI to the installation. We continued testing new sensor technology for surface and ground water monitoring and results are provided below.

2.2.2 Land Cover

Currently we have land cover maps based on imagery from 1999 and 2001. We have re-evaluated both maps to compare the spread of the urban areas around Fort Benning and the cantonment area. We have developed land cover metrics for both maps using fragmentation statistical techniques. The 2003 image has been purchased and will be developed during 2004.

2.2.3 Aquatic

The aquatic monitoring plan was revised per TAC direction and peer reviewed during 2003. Formal collaboration with Dr. James Gore (CSU Columbus), including data sharing, has been established and begun. The revised plan was officially implemented on Fort Benning during autumn 2003.

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[1] Kress, M. Rose. 2001. *Long-Term Monitoring Program, Fort Benning, GA; Ecosystem Characterization and Monitoring Initiative, Version 2.1*. ERDC/EL TR-01-15, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

2.2.4 Erosion and Deposition

Data from the erosion deposition component have been analyzed and summarized within the context of the milestones to "evaluate the balance between biotic and abiotic components of ECMI," and "…justification for the erosion/deposition component of ECMI." We are recommending that additional analysis of the data be conducted during FY04 and that the plots not be measured in FY04 in order to put more emphasis on implementing the woody productivity component.

2.2.5 Woody Productivity

Additional emphasis has been placed on implementing the woody productivity component in conjunction with Fort Benning's Forest inventory procedure. Fort Benning's revised forest inventory procedure was implemented in FY03 and analysis of woody productivity was begun by the ECMI team. This analysis effort was initiated within the context of the milestone to evaluate the balance between biotic and abiotic components.

2.3 Important Findings and Results for FY03

2.3.1 Meteorology

The meteorology stations have performed very well since summer 1999. Aside from recommended routine maintenance, they require very little attention. Two technical reports have been published. The first describes the meteorology stations, the hydrology stations, and the ground water wells, the specifications for each and summarized data.[2] The second report describes an evaluation of the instrumentation and initial tests of newer sensors. Currently we recommend no change in to the existing meteorological instrumentations.[3] (All SEMP/ECMI reports can be downloaded from the web site listed below under SEMP/ECMI Publications.) Figure 2-1 is an example data summary for one station for August 2002.

[2] Hahn, C. D., and Leese, D. L. (2002). Automated environmental data collection at Fort Benning, Georgia, from May 1999 to July 2001, ERDC TR-02-3, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

[3] Hahn, D. Charles. 2002. Evaluation of ECMI Instrumentation Deployed at Fort Benning, GA. ERDC/EL TN-ECMI-02-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Data from several of the meteorological parameters have been examined over the period from summer 1999 through spring of 2003. These parameters include air temperature, and precipitation. Table 2-1 presents the maximum and minimum seasonal air temperatures. These are the extreme maximum and minimum temperatures recorded. Table 2-2 presents the average daily maximum and minimum daily temperatures. Figure 2-2 illustrates the average maximum daily temperature averaged over the season. Figure 2-3 shows the average daily minimum temperature averaged over the season.

ECMI Meteorological Station Data Monthly Summary Sheet				
Met Station ID: ME08 - Malone Range (Range # 22)				
Time Period Covered: August 2002 - Number of Observations: 1488				
Meteorological Station Height: approximately 10 feet	Wind Sensors: 3.0 meters	Air Temp Sensor: 1.5 meters	UTM Easting: 701525	UTM Northing: 3593400
Variable Measured (Unit of Measure)	Mean	Std Error	Minimum	Maximum
Air Temperature *(Degrees Celsius)*	26.2	0.1	16.1	37.4
Relative Humidity *(Percent Humidity)*	70.0	0.5	23.0	99.0
Barometric Pressure *(MilliBars)*	1019.8	0.1	1013.0	1028.0
Solar Radiation *(Watts / Square Meter)*	218.9	7.4	0.0	947.0
Wind Speed *(Meters / Second)*	0.9	0.0	0.0	3.6
Wind Direction *(Degrees from North)*	145.0	2.8	0.1	360.0
Precipitation *(Millimeters)*	0.0	0.0	0.0	11.8

Figure 2-1. Sample data summary.

Figure 2-4 presents the monthly precipitation totals for the stations and Figure 2-5 represents the seasonal precipitation totals. It is important to note that during the June 2001 period, the rain gauge at McKenna MOUT site was clogged with debris and failed to accurately report precipitation.

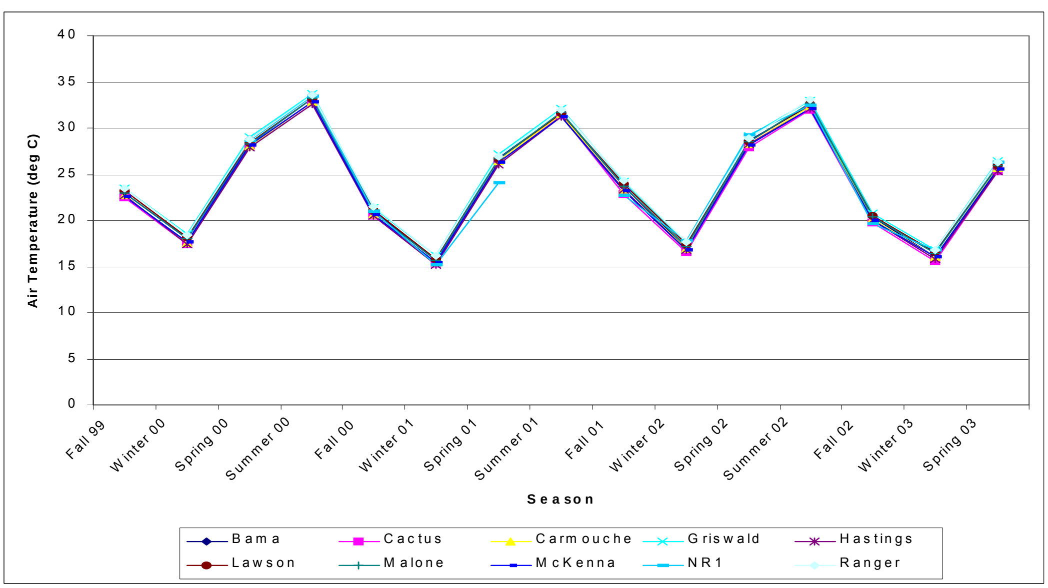

Figure 2-2. Average Daily Maximum Temperature

Table 2-1. Seasonal maximum and minimum air temperature (deg C).

Season	Bama	Cactus	Carmouche	Griswald	Hasting	LAAF	Malone	McKenna	NR1[1]	Ranger
Maximum										
Summer 99	38.5	37.7	37.8	39.3	38.6	40.4	43.2	37.8	N/I	37.7
Fall 99	31.7	31.2	31.9	32.6	31.8	32.2	31.6	31.0	N/I	32.9
Winter 00	27.7	27.5	27.1	27.9	26.7	27.3	27.2	27.1	N/I	28.1
Spring 00	36.0	35.7	35.0	36.4	35.2	35.5	36.2	35.4	36.9	36.3
Summer 00	40.2	39.6	39.5	41.9	39.1	40.4	40.5	39.8	40.6	39.9
Fall 00	32.0	31.5	31.7	31.9	31.7	32.0	31.6	31.3	32.1	32.1
Winter 01	25.9	25.2	25.5	25.9	25.6	26.0	25.8	25.3	26.0	26.5
Spring 01	33.0	33.4	32.9	33.6	32.2	33.0	33.3	32.6	30.7	32.9
Summer 01	35.5	35.0	35.2	36.3	35.0	35.6	36.3	35.1		35.6
Fall 01	32.2	32.2	32.7	33.5	32.7	32.6	32.9	31.9	29.9	32.6
Winter 02	30.6	29.2	30.1	31.1	30.3	31.6	30.2	29.7	30.0	31.7
Spring 02	36.5	35.1	36.0	36.8	35.8	36.2	36.8	35.8	36.7	36.0
Summer 02	36.6	36.4	37.1	38.2	36.7	37.1	37.8	36.4	37.1	37.1
Fall 02	33.2	32.8	33.2	34.1	32.4	33.4	34.0	33.2	33.0	
Winter 03	27.5	27.4	27.7	29.2	27.0	28.0	28.8	27.6	28.4	28.7
Spring 03	32.1	31.5	32.0	32.9	31.8	31.9	31.8	31.9	31.9	32.1
Minimum										
Summer 99	9.6	13.0	10.6	8.9	12.8	11.2	10.6	10.1	N/I	8.4
Fall 99	-4.2	-1.7	-4.0	-4.6	-3.5	-4.3	-4.0	-3.3	N/I	-5.0
Winter 00	-7.3	-6.7	-7.2	-7.1	-7.5	-7.8	-7.3	-7.1	N/I	-8.1
Spring 00	-0.6	0.9	-0.3	-1.0	-0.2	-0.1	-1.1	-0.5	-0.4	-1.6
Summer 00	11.7	12.6	12.4	11.4	12.2	12.8	12.2	11.4	12.7	10.2
Fall 00	-9.5	-10.1	-9.8	-8.9	-10.2	-9.2	-9.4	-9.1	-9.3	-9.3
Winter 01	-9.9	-8.5	-9.7	-9.9	-8.6	-10.7	-9.8	-10.1	-8.2	-11.4
Spring 01	-0.4	2.1	0.5	-0.2	0.1	-0.5	-0.8	0.4	-1.2	-0.8
Summer 01	9.3	11.3	10.6	9.9	10.5	9.7	10.5	10		9.5
Fall 01	-4.4	0.2	-3.2	-4.1	-3.7	-4.6	-3.7	-3.4	-4.4	-4.4
Winter 02	-9.0	-6.9	-8.7	-9.2	-8.6	-10	-9.4	-8.7	-7.5	-10.0
Spring 02	-3.0	-0.3	-2.9	-3.1	-2.8	-3.9	-2.9	-2.1	3.4	-4.3
Summer 02	14.6	17.8	15.0	14.9	14.5	13.9	13.9	15.3	15.6	15.6
Fall 02	-5.3	-2.8	-5.2	-5.3	-5.4	-5.6	-5.6	-5.1	-4.4	
Winter 03	-11.7	-12.6	-11.9	-11.2	-12.4	-11.6	-11.8	-11.6	-11.5	-10.5
Spring 03	-1.5	-0.1	-1.1	-1.7	-0.3	-1.9	-1.4	0.1	-0.3	-1.7

1 N/I = Not Installed. Natural Resources Station not installed until 15 March 2000.

Table 2-2. Average daily maximum and minimum air temperatures.

Season	Bama	Cactus	Carmouche	Griswald	Hasting	LAAF	Malone	McKenna	NR1[1]	Ranger
Maximum										
Summer 99	32.97	32.01	32.54	33.43	32.38	33.33	32.74	32.46	N/I	32.96
Fall 99	22.98	22.45	22.73	23.46	22.75	23.24	22.91	22.60	N/I	23.48
Winter 00	18.03	17.39	17.52	18.49	17.46	18.21	18.02	17.66	N/I	18.45
Spring 00	28.75	28.18	28.06	29.05	27.92	28.45	28.32	28.19	28.69	28.78
Summer 00	33.54	32.80	32.79	33.75	32.54	33.26	33.21	32.88	33.47	33.55
Fall 00	20.96	20.50	20.57	21.38	20.44	21.15	20.89	20.66	20.95	21.46
Winter 01	15.64	15.30	15.41	16.19	15.24	15.79	15.65	15.46	15.20	16.23
Spring 01	26.76	26.42	26.47	27.17	26.09	26.71	26.66	26.35	24.10	26.94
Summer 01	31.57	31.38	31.44	32.11	31.24	31.59	31.67	31.25		31.96
Fall 01	23.75	22.88	23.37	24.14	23.36	23.98	23.66	23.27	22.73	24.29
Winter 02	16.95	16.54	16.90	17.53	16.82	17.38	17.17	16.84	17.80	17.65
Spring 02	28.59	27.84	28.30	29.10	28.29	28.56	28.47	28.15	29.22	28.92
Summer 02	32.45	31.96	32.38	32.93	32.14	32.57	32.70	32.14	32.49	33.03
Fall 02	20.34	19.74	20.09	20.73	19.97	20.45	20.41	20.03	19.62	
Winter 03	16.08	15.57	16.05	16.73	15.76	16.49	16.48	16.03	16.83	16.80
Spring 03	25.32	25.27	25.70	26.43	25.28	25.97	25.92	25.57	26.25	26.32
Minimum										
Summer 99	19.06	20.11	19.66	19.55	19.11	19.69	19.35	19.78	N/I	18.94
Fall 99	8.54	11.52	9.25	8.72	9.28	8.53	9.22	9.28		8.17
Winter 00	3.88	6.14	4.42	3.90	4.75	3.23	4.48	4.56		3.27
Spring 00	13.32	15.18	14.01	13.73	14.19	13.34	13.77	14.18	14.31	13.02
Summer 00	19.84	21.07	20.33	20.37	20.22	20.19	20.03	20.42	20.66	19.66
Fall 00	7.20	9.67	7.56	7.45	7.65	7.22	7.44	7.60	8.08	6.93
Winter 01	3.08	4.65	3.56	3.26	3.55	2.58	3.47	3.55	3.61	2.77
Spring 01	13.20	14.90	13.78	13.46	13.72	12.88	13.37	13.82	11.82	12.80
Summer 01	19.96	20.95	20.54	20.46	20.14	20.09	20.11	20.49		20.10
Fall 01	8.17	12.33	9.19	8.19	9.07	7.56	9.03	8.92	8.61	7.80
Winter 02	2.69	5.40	3.73	3.07	3.68	1.94	3.53	3.53	4.43	2.44
Spring 02	14.33	16.07	15.03	14.76	14.51	14.08	14.61	15.02	16.08	14.09
Summer 02	20.52	21.34	21.08	21.14	20.62	20.61	20.64	21.09	21.22	20.69
Fall 02	9.84	10.90	9.70	9.88	9.51	9.58	9.44	9.88	8.92	
Winter 03	3.69	5.06	3.93	3.85	4.13	3.25	3.89	4.09	4.89	3.88
Spring 03	11.92	14.60	13.47	13.28	13.54	12.57	13.04	13.67	14.31	13.20

[1] N/I = Not installed. Natural Resources Station not installed until 15 March 2000.

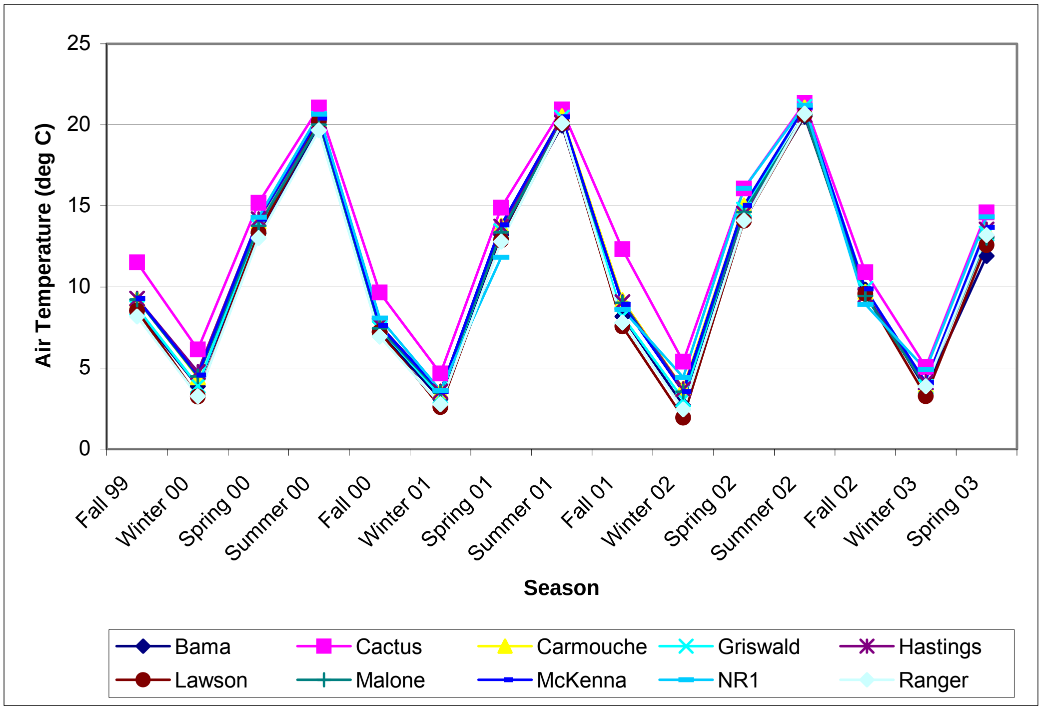

Figure 2-3 Average daily minimum air temperature.

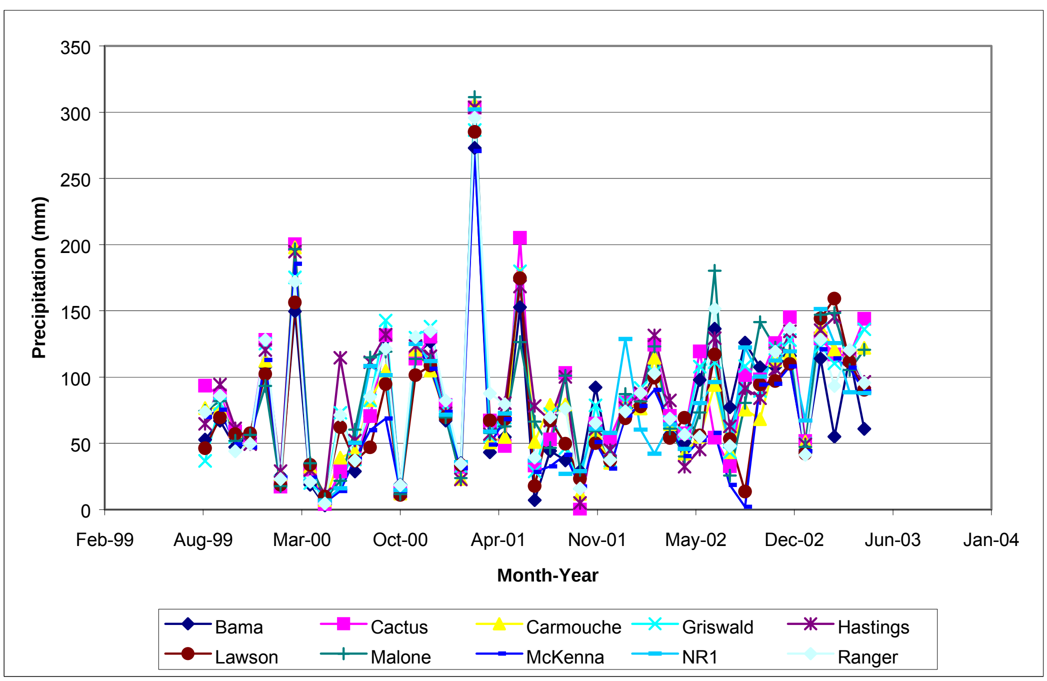

Figure 2-4. Monthly precipitation totals.

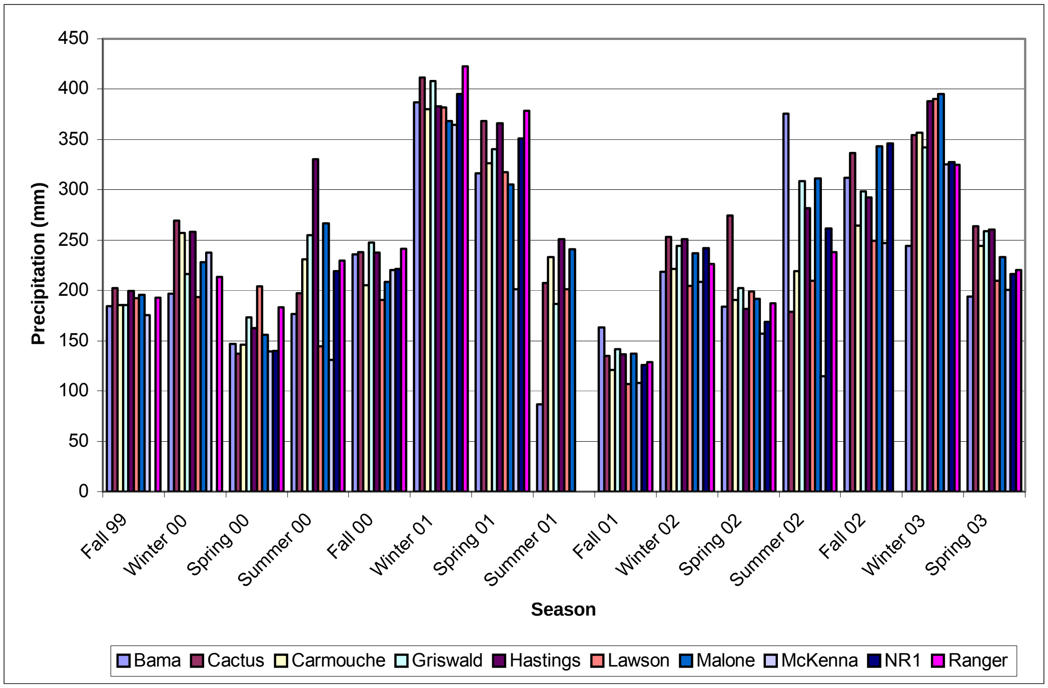

Figure 2-5. Season precipitation totals.

2.3.2 Surface Water

The automated hydrological stations have been maintenance intensive. Aside from problems caused by the drought and low stream flows, sedimentation in and around the sensor packages has caused problems and the dissolved oxygen (DO) sensor did not perform to specifications.[4] We are working with vendors and testing more reliable sensors for the future. Since October 2002 we have been testing discrete turbidity, DO, pH, and conductivity sensors.[5] Some problems surfaced with the power supplies for the pH and conductivity probes; however, these problems have been resolved. The discrete DO sensor has been deployed and compared with the original DO sensor in the Hydrolab; the results have been promising. The two probes have been within the margin of error for each probe in side-by-side comparisons. Currently only temperature, flow, and level are monitored with the automated stations and all water quality data are

[4] Hahn, C. D., and Leese, D. L. (2002). Automated environmental data collection at Fort Benning, Georgia, from May 1999 to July 2001, ERDC TR-02-3, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

[5] Hahn, D. Charles. 2002. Evaluation of ECMI Instrumentation Deployed at Fort Benning, GA. ERDC/EL TN-ECMI-02-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

collected manually every 2 weeks and just after significant events. This current procedure minimizes routine and non-routine maintenance time until more reliable sensors can be evaluated.

Data from each of the surface water parameters were examined. These parameters included water stage, water temperature, pH, turbidity, dissolved oxygen (DO), specific conductivity, and water velocity. Data automatically collected with the Hydrolab datasondes at the Bonham Creek, Sally Branch, and Upatoi stations will not be presented here; it is presented in a previous report discussing these data.[6] Daily averages of water stage, velocity, and temperature were calculated and plotted for the data available. Water stage data are referenced to the sensor, which was located very near the bottom of the water column (<5 cm above the stream bed). Figure 2-6 and Figure 2-7 present the water stage data for Bonham Creek and Sally Branch Creek.

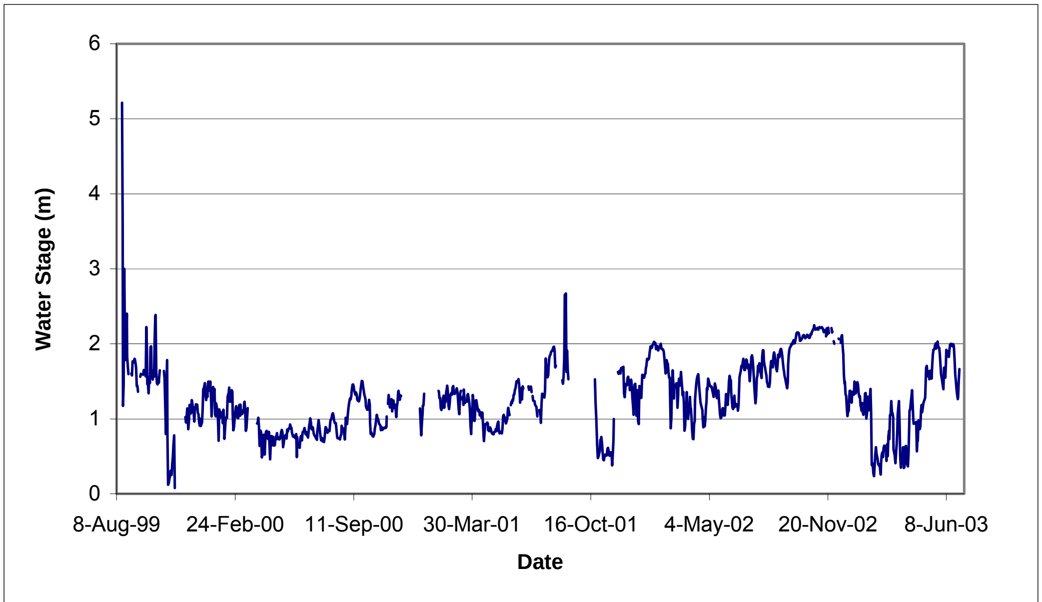

Figure 2-6. Water stage at Bonham Creek.

[6] Hahn, C. D., and Leese, D. L. (2002).

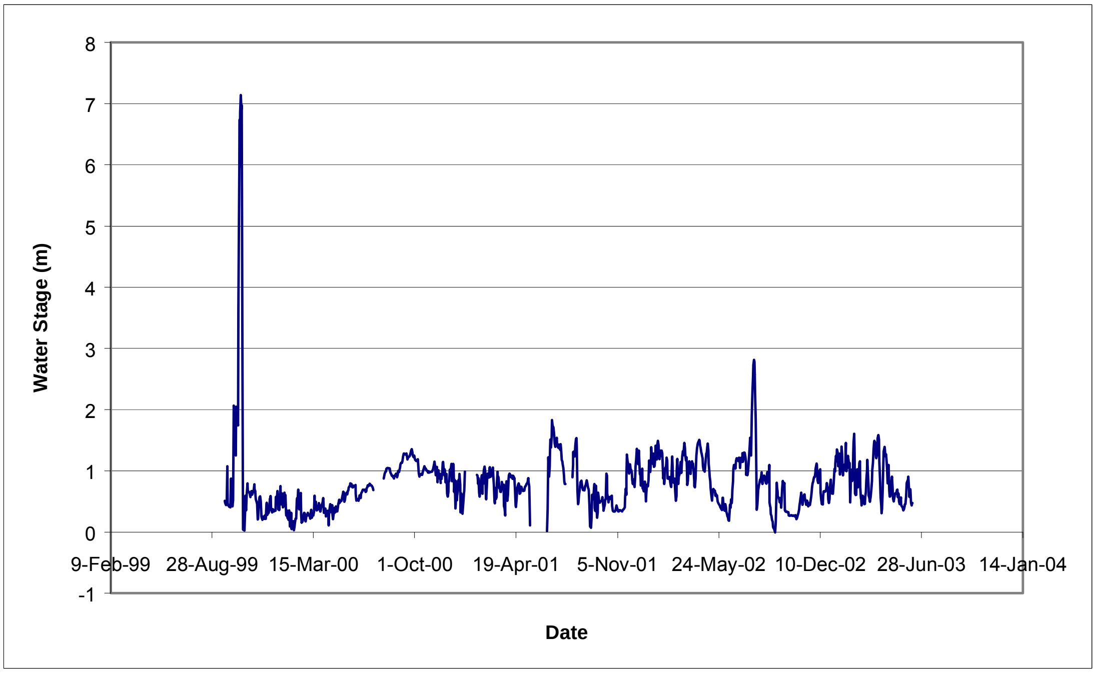

Figure 2-7. Water stage at Sally Branch Creek.

Figure 2-8 presents water velocity data. Due to the general lack of water at Randall Creek, no velocity sensor was installed at that station. Figure 2-9 presents water temperature data. At Bonham Creek, Sally Branch, and Upatoi Creek, water temperature data originally were collected with the Hyrdolab datasonde and those data are not included in this graph.

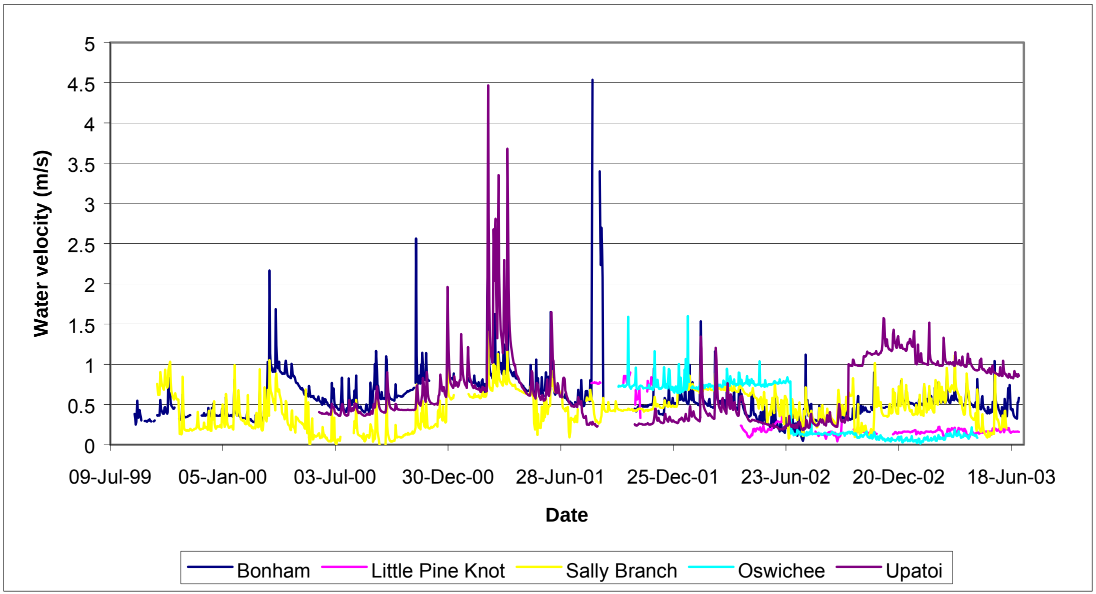

Figure 2-8. Average daily water velocity.

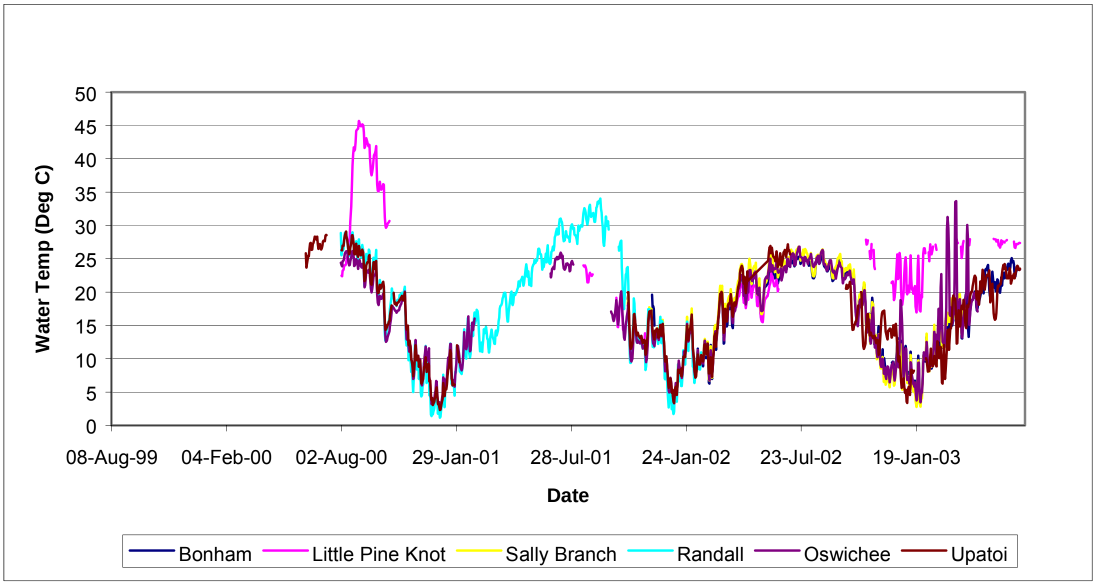

Figure 2-9. Average daily water temperature.

Manual Sampled Water Quality Data

Beginning in June 2001, a decision was made to manually sample the water quality data using Hydrolab datasondes. The sondes were calibrated prior to each sampling mission as part of the standard operating procedure. Data were to be collected at 2-week intervals at each of the six water stations. Table 2-3 and Table 2-4 present those manually sampled data at Bonham Creek and Sally Branch.

Table 2-3. Manually sampled water quality data a Bonham Creek.

Date	DO%	DO (mg/l)	Ph	Water Temp (Deg C)	Depth (m)	Specific Conductivity (mS)	NO_3 (mg/l as N)	Turbidity (NTU)	Comments
7/25/01	90.5	7.51	4.32	23.90	0.30	16.0	NR		
8/10/01	91.5	7.65	4.00	24.10	0.78	16.0	NR		
8/24/01	83.4	7.24	4.01	22.30	0.79	16.0	NR		
9/10/01	87.5	7.42	3.37	23.00	0.82	15.0	0.03		
9/24/01	94.3	8.15	3.78	21.80	0.70	15.0	NR		Rain, NO_3 probe failed
10/10/01	82.0	8.08	3.94	16.10	0.70	14.0	0		
10/23/01	79.6	7.83	3.93	15.64	1.00	16.0	0		
11/2/01	83.6	8.67	3.82	13.60	0.85	15.0	0		
11/21/01	80.3	9.34	4.63	8.48	1.07	16.0	0		
12/7/01	80.5	8.46	3.19	13.54	0.99	18.0	0		
12/21/01	91.4	10.68	4.98	7.97	0.98	18.0	0		
1/3/02	95.3	12.43	4.97	4.24	0.92	17.0	0		Snowing
1/18/02	93.8	11.08	3.95	8.57	0.98	21.0	0		

Date	DO%	DO (mg/l)	Ph	Water Temp (Deg C)	Depth (m)	Specific Conductivity (mS)	NO_3 (mg/l as N)	Turbidity (NTU)	Comments
2/1/02	83.2	7.94	3.95	16.50	1.03	17.6	0		
2/15/02	89.4	10.43	4.52	8.58	0.59	16.1	0		
3/1/02	95.8	11.85	4.56	6.27	0.91	14.9	0		
3/15/02	84.3	8.41	3.81	15.20	0.66	20.0	0		
3/29/02	93.5	9.11	3.50	15.90	0.77	12.2	0		
4/12/02	84.1	7.97	4.25	17.99	0.66	11.4	0		
4/26/02	82.2	7.83	4.61	17.78	0.71	14.1	0		
5/10/02	71.5	6.72	4.94	18.38	0.59	10.6	0		
5/24/02	80.2	8.10	4.99	16.20	0.67	8.9	0		
6/7/02	73.7	6.34	4.44	22.99	0.64	11.0	0		
6/21/02	84.3	7.29	4.37	22.29	0.71	10.7	0		
7/8/02	85.1	7.04	4.76	24.65	0.66	11.1	0		
7/26/02	82.5	6.93	4.09	24.29	1.04	15.6	0		
8/9/02	77.8	6.81	5.04	21.90	0.95	11.6	0		
8/23/02	87.5	7.29	5.38	24.90	0.77	6.4	0		
9/6/02	84.1	7.29	5.03	23.10	0.60	11.7	0		
9/20/02	69.8	5.71	6.92	24.40	0.99	33.9	0		
10//4/02	79.1	6.96	4.70	22.70	0.20	16.6	0		
10/18/02	80.8	8.37	4.91	13.90	0.29	18.6	0		
11/1/02	83.2	8.54	4.39	14.20	0.64	17.6	0	16.5	Turbidity added
11/15/02	80.8	8.37	4.49	11.30	0.50	20.3	0	21.8	
11/27/02	89.3	9.89	4.77	10.90	0.40	17.8	0	5.3	
12/13/02	75.3	8.65	4.83	9.22	1.00	17.3	0	24.0	
12/24/02	93.5	10.01	4.69	13.00	1.51	17.3	0	50.1	
1/9/03	96.1	10.01	4.64	11.14	0.77	23.3	0	86.8	
1/24/03	82.1	11.05	4.27	3.15	0.47	4.7	0	8.7	
2/7/03	92.9	10.28	4.34	8.93	0.86	24.2	0	16.0	
2/24/03	85.7	9.20	4.16	11.73	0.48	15.9	0	11.8	
3/7/03	85.6	8.79	4.29	14.50	1.08	12.2	0	226.5	
3/21/03	86.8	8.57	4.39	16.80	0.48	7.0	0	15.6	
4/4/03	86.1	8.43	4.33	16.24	0.60	7.0	0	19.6	
4/18/03	82.5	7.60	4.49	18.93	0.50	12.0	0	49.7	
5/7/03	90.5	7.82	4.39	22.70	0.43	7.0	0	3.7	
5/25/03	91.6	8.43	4.19	19.40	0.95	7.0	0	21.7	
6/13/03									
7/03//03	83.2	7.15	4.14	23.54	0.75	0.0	0	26.5	
7/16/03	75.5	6.41	4.25	24.14	0.88	0.0	0	26.5	
7/26/03	83.4	6.97	4.51	24.10	0.52	0.0	0	20.8	
8/11/03	86.7	7.07	4.13	24.88	0.82	0.0	0	15.1	
8/28/03	81.3	6.86	4.35	25.13	0.79	0.0	0	21.4	

Table 2-4. Manually sampled water quality data at Sally Branch.

Date	DO%	DO (mg/l)	Ph	Water Temp (deg C)	Depth (m)	Specific Conductivity (mS)	NO_3 (mg/l as N)	Turbidity (NTU)	Comments
7/25/01	90.9	7.51	5.15	25.00	0.29	18.0	NR		
8/10/01	89.9	7.55	4.25	25.20	0.46	17.0	NR		
8/24/01	88.5	7.52	4.60	23.10	0.46	14.0	NR		
9/10/01	87.0	7.32	3.45	23.90	0.52	16.0	0.04		
9/24/01	85.5	7.38	3.78	22.60	0.60	20.0	NR		Rain, NO_3 Probe Failed
10/10/01	78.5	7.74	4.04	16.10	0.58	17.0	0		
10/23/01	80.1	8.05	4.06	15.99	0.53	20.0	0		
11/2/01	82.4	8.67	3.98	13.13	0.55	19.0	0		
11/21/01	81.0	9.41	4.59	7.90	0.64	22.0	0		
12/7/01	87.4	9.24	3.14	13.01	0.54	24.0	0		
12/21/01	97.1	11.64	4.82	7.53	0.57	24.0	0		
1/3/02	107.7	14.54	4.72	3.27	0.57	27.0	0		Snowing
1/18/02	96.5	11.43	3.79	7.87	0.51	30.0	0		
2/1/02	84.5	8.12	3.86	17.20	0.63	22.7	0		
2/15/02	91.6	10.79	4.34	8.14	0.32	24.1	0		
3/1/02	89.7	11.25	4.48	5.86	0.36	20.7	0		
3/15/02	88.5	8.92	3.76	15.70	0.39	31.3	0		
3/29/02	91.1	8.92	3.76	15.70	0.43	15.6	0		
4/12/02	84.2	7.86	4.24	18.90	0.47	20.3	0		
4/26/02	81.3	7.73	4.63	18.20	0.40	14.3	0		
5/10/02	81.7	7.61	5.91	19.10	0.43	9.2	0		
5/24/02	73.9	7.15	5.00	16.80	0.19	8.6	0		Beaver dam at road crossing breached lowering water level
6/7/02	74.0	6.22	4.53	24.47	0.45	11.1	0		Road crossing culvert blocked
6/21/02	80.9	6.92	5.04	23.30	0.41	9.2	0		
7/8/02	75.8	6.23	5.37	25.64	0.40	11.0	0		Road crossing culvert unblocked
7/26/02	84.5	6.94	4.81	25.72	0.37	11.6	0		
8/9/02	69.7	6.02	6.11	22.46	0.27	9.8	0		
8/23/02	78.1	6.43	5.67	25.70	0.39	2.4	0		
9/6/02	82.0	6.91	5.36	23.90	0.19	10.3	0		
9/20/02	79.6	6.77	6.13	25.20	0.27	21.5	0		
10/4/02	72.8	6.25	4.93	23.10	0.29	18.2	0		
10/18/02	85.4	8.93	5.12	13.60	0.24	20.2	0		
11/1/02	92.2	9.63	4.41	13.97	0.23	21.6	0	4.4	Turbidity added
11/15/02	85.4	8.93	4.00	10.50	0.18	30.8	0	0.0	
11/27/02	96.1	10.57	3.35	9.90	0.17	30.3	0	0.0	
12/13/02	77.6	9.14	4.57	8.51	0.61	28.0	0	0.0	
12/24/02	88.2	9.67	4.27	12.40	0.68	28.6	0	151.1	
1/9/03	98.0	11.05	3.58	10.70	0.41	37.0	0	32.6	

Date	DO%	DO (mg/l)	Ph	Water Temp (deg C)	Depth (m)	Specific Conductivity (mS)	NO_3 (mg/l as N)	Turbidity (NTU)	Comments
1/24/03	109.2	13.80	4.15	2.00	0.27	34.7	0	1.7	
2/7/03	99.0	11.40	4.51	9.06	0.54	34.2	0	0.0	
2/24/03	82.1	8.70	3.51	13.12	0.50	23.7	0	21.8	
3/7/03	87.2	8.76	4.19	15.99	0.61	17.2	0	5.1	
3/21/03	85.2	7.98	4.42	18.32	0.61	5.0	0	10.2	
4/4/03	85.2	8.25	4.04	16.80	0.37	9.0	0	16.8	
4/18/03	77.2	7.01	4.51	20.20	0.41	9.0	0	1.6	
5/7/03	88.0	7.28	3.98	24.50	0.21	5.0	0	0.0	
5/25/03	94.2	8.80	4.03	20.00	0.55	10.0	0	114.3	
6/13/03									
7/03//03	78.4	6.03	4.46	23.06	0.66	0.0	0	12.5	
7/16/03	80.0	6.53	4.20	26.03	0.20	0.0	0	2.1	
7/26/03	89.7	7.40	4.39	25.37	0.12	0.0	0	9.3	
8/11/03	95.2	7.71	4.88	26.10	0.22	0.0	0	7.8	
8/28/03	85.8	6.85	4.69	26.31	0.09	0.0	0	8.2	

2.3.3 Ground Water

Five wells were drilled during June 2001 to monitor the shallow alluvial aquifers. The Bonham Creek site was dry with no indication of subsurface water down to a depth of 55 feet. The well site was within 100 feet of the main streambed. Four successful wells were drilled in Little Pine Knot, Oswichee, Randall, and Sally Branch Creeks. These wells were instrumented with In-Situ Mini-Trolls to measure ground water temperature and level.[7] The Mini-Trolls have been very dependable since deployment and we recommend no changes to the ground water instrumentation at this time.[8]

Initial analysis of the ground water data indicate that ground water temperature and level profiles, as investigated during the sampling window of June 2001 through September 2003, varied over sampling locations and seasons of the year. The ground water parameters associated with the sampling site of Oswichee Creek exhibited the largest values; whereas, Sally Creek exhibited the smallest values in both water temperature and level when studying the minimum value

[7] Hahn, C. D., and Leese, D. L. (2002). Automated environmental data collection at Fort Benning, Georgia, from May 1999 to July 2001, ERDC TR-02-3, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

[8] Hahn, D. Charles. 2002. Evaluation of ECMI Instrumentation Deployed at Fort Benning, GA. ERDC/EL TN-ECMI-02-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

regimes, the maximum value regimes, and the average regimes. The profiles at Little Pine Knot and Randall Creek fell between these two extremes. Seasonal variation was present and varied with respect to the parameter being measured. Results of additional analysis will be reported in a technical report in FY04.

2.3.4 Aquatic

We are using the Rapid Bioassessment Protocols (RBP) to study streams at Fort Benning, an 182,000-acre military reservation near Columbus, Georgia. The purpose is to develop the aquatic component of an ecosystem-monitoring program that will be passed on to base personnel to monitor, protect, and preserve lotic systems. The reservation is along the fall line in eastern Georgia and is within two sub-ecoregions of the Southern Plains: Sand Hills and Southeastern Plains and Hills.

In spring 2003, we sampled 27 100-m reaches in 1st to 5th order streams. In each we measured pH, DO, specific conductance, rated stream habitat characteristics, and collected a 5-min macroinvertebrate sample. Preliminary analyses indicated that streams fit into three categories: low pH (4 to 5) with moderately high percent coarse woody debris (CWD) (40-85%), moderate pH (5 to 6) with moderately low percent CWD (10-40%), and moderate to high pH (>6) with low percent CWD (<10%, see Figure 2-10). Substratum in the majority of the streams consisted of sand with little or no coarse-grained material. Chironomidae dominated in low pH reaches (>70%) but were less abundant in the high pH reaches (<40%). Trichoptera, ephemeroptera, and plecoptera were uncommon in all reaches, presumably because of low pH, little CWD, or lack of coarse-grained substratum. Stream pH and CWD appear to be most important in structuring the macroinvertebrate assemblage, which is unrelated to sub-ecoregion characteristics.

When comparing results of the physical metrics (stream quality) from our studies at Fort Benning (Figure 2-11), with those of Dr. James Gore from the Sand Hills Sub-ecoregion (Figure 2-12) it is apparent that our data is considerably more variable than his from the reference streams.

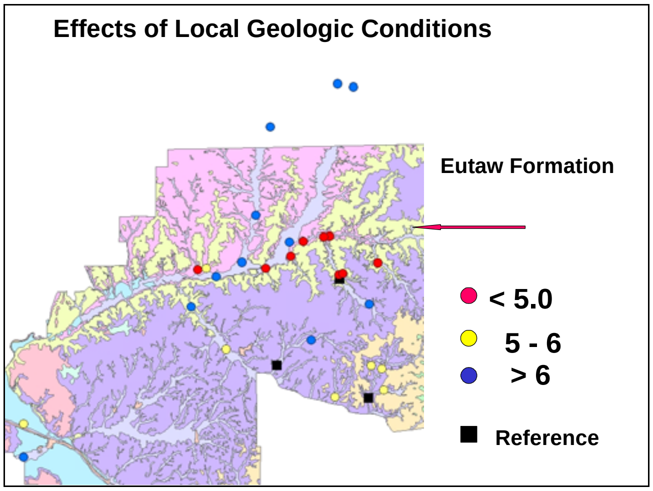

Figure 2-10. Relationship between pH of the streams and soil types at Fort Benning, GA.

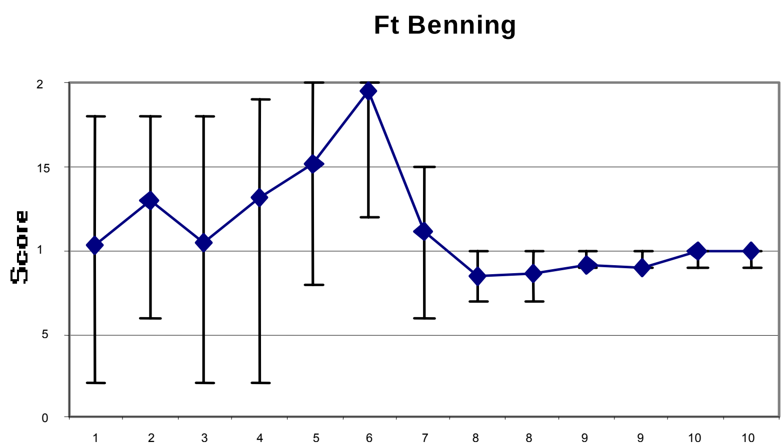

Figure 2-11. Results of the physical metrics (stream quality) from our studies at Fort Benning, GA.

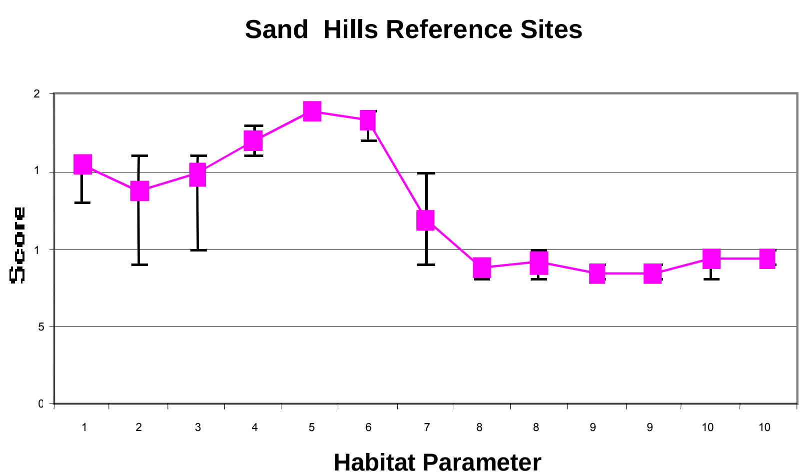

Figure 2-12. Results of the physical metrics (stream quality) with Dr. James Gore's results from the Sand Hills sub-ecoregion.

2.3.5 Land Cover

We have generated land cover maps based on LandSat TM imagery from 1999 and 2001. We have used these data sets to determine the amount of urban expansion in areas adjacent to Fort Benning and for the cantonment area on Fort Benning. From 1999 to 2001 we estimate that approximately 3,700 hectares were urbanized (data not shown in table). We also used fragmentation statistical techniques to make comparisons between years based on forest area landscape metrics provided in Table 2-5. This type of metric can be used to determine the degree that a landscape meets specific habitat requirements for target species. In summary, the metrics below indicate that there has been a reduction in core forest area on Fort Benning; however, the change has not been as significant as the change outside Fort Benning within the HUC. The ECMI team is now developing a manuscript for a refereed journal that will develop the relationships between changes in forest habitat and habitat requirements of native song birds of the region that are dependent on interior forest habitat. We plan to submit the manuscript in May 2004.

Table 2-5. Landscape metrics based on fragmentation statistics generated from Landsat TM images (from 1999 and 2001)

Inside the Installation	**1999**	**2001**	**Change**
Forested Area (ha)	50,897	51,516	619
Number of Patches	510	775	265
Core Area (ha)	29,279	25,916	-3,363
Edge Density (m/ha)	45	56	11
Outside the Installation (HUC)	**1999**	**2001**	**Change**
Forested Area (ha)	53,420	53,027	-393
Number of Patches	1503	2585	1082
Core Area (ha)	27,531	20,565	-6,965
Edge Density (m/ha)	41	58	17

2.3.6 Erosion and Deposition

During FY03 the ECMI Team completed an initial evaluation of the soil erosion/deposition component within the context balancing the abiotic and biotic components of ECMI. Our initial conclusions are that the erosion/deposition data are spatially explicit in three dimensional space (Figure 2-13) and therefore, very useful data for developing initial parameters necessary for distributive watershed simulation models that are capable of simulating erosion, sediment transport and deposition, and channel routing. From a scientific and statistical standpoint the design of this component is sound and defensible; however, from the practical standpoint of the installation land managers, a simpler and faster method to monitor erosion and deposition in areas of high interest—sand box areas—may be more important for their long-term monitoring needs.

Based on these initial conclusions we have recommend that we do not remeasure the erosion plots using the current method in 2004 and use those funds to augment the process of fully implementing the woody productivity component of ECMI in conjunction with the installation forest inventory process. We will confer with the installation land managers and determine their current and future need for erosion/deposition monitoring and the priority level. If it is determined that there is a priority need, we can then work with the installation personnel and their local partners in the Natural Resources Conservation Service to adapt the erosion monitoring scheme that better fits their practical needs. During 2004 we plan to continue to evaluate the erosion/deposition data collected between 2001 and 2003 and determine if and on what timeframe the original method should be implemented. This may largely depend on the need to make use of distributive watershed models in the future.

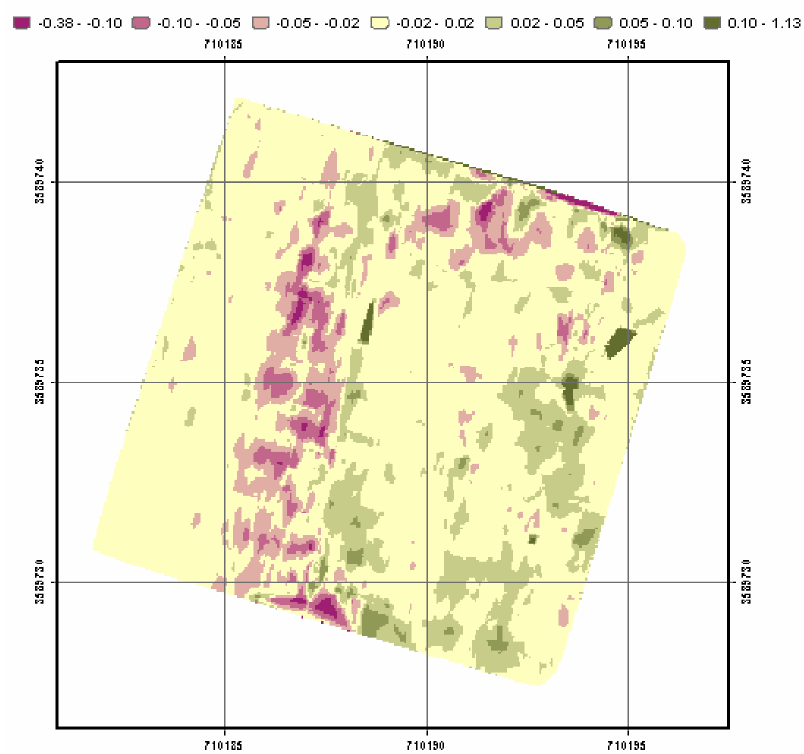

Figure 2-13. Surface elevation difference plot from April 2001 and April 2002.

2.3.7 Woody Productivity

The woody productivity component was implemented during FY03 in cooperation with the Fort Benning Land Management Branch (LMB) personnel. Woody productivity is being derived, in part, using data from the Forest Inventory procedure used by Fort Benning personnel. Additional data are also available from SEMP research projects on Fort Benning. The procedure will provide a watershed-level and an installation-wide estimate of woody productivity and will support both the installation and research group needs. During summer 2003, forest inventory data were collected in the Delta 14 and 15 compartments that represent a portion of the area where ECMI long-term monitoring is being conducted. Data from additional compartments will be provided to the ECMI team as they are collected per Fort Benning's inventory schedule during autumn 2003. Based on a feasibility analysis[9] we plan to develop an estimate of woody productivity for the Fort Benning installation during FY04.

2.3.8 Challenges

The process of transitioning the SEMP ECMI technology to Fort Benning and other DOD installations as well as cost reductions for long-term monitoring will be implemented during FY04 with a scheduled completion in FY06. Close coordination with the SEMP technology transition team and the SEMP research teams will be required to effect this process.

Scheduled Date	Milestone Description	POC
	Monitoring	
Sep 04	Draft Technical Report: Analysis of monitoring data 1999-2003	Price, Kress
May 04	Journal Submission: The Rapid Bioassessment Protocols: An Approach to Monitoring, Managing, and Protecting Aquatic Habitats on Military Installations	Miller, Lee, Kress, Price
May 04	Journal Submission: Habitat Fragmentation, Fort Benning, GA	Anderson, Bourne, Guilfoyle
Apr 04	Cost reduction and task transition options for long-term monitoring	Price, Kress
Jan 04	Published Technical Report: “Phase II ECMI Status and Progress”	Price, Kress, and others

[9] O'Neil, L. J., Lee, A., and Price, D. (2003). Terrestrial Productivity at Fort Benning, GA; A Feasibilty Analysis: Ecosystem Characterization and Monitoring Initiative, ERDC/EL TN-ECMI- XX-XX, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

2.4 Publications and Presentations

Submitted

Anderson, Drew, Elizabeth Lord, and Scott Bourne. (2003). SEMP Data Repository Operations. ERDC/EL TR XX-XX, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

National Presentation

Price, D.L., and M.R. Kress. 2000. Ecosystem Characterization and Monitoring Initiative: An Ecological Baseline for Installations. 92nd Annual Meeting of the American Society of Agronomy. Minneapolis, Minnesota. November 2000.

3 Historic Land Use and Climatic Analysis

Dr. Harold E. Balbach, ERDC, Construction Engineering Research Laboratory, Champaign, IL

The basis of the SEMP studies at Fort Benning lies with the evaluation of data as found during the study period 1999-2004, combined with that acquired during the monitoring period. This monitoring period (at least 1999-2010) is intended to be long enough that random year-to-year weather variation is minimized. Further, some vital aspects of vegetation and soil condition must be the result of human actions which took place long before the SEMP study. Army use of the terrain of Fort Benning started in 1918 for the western part of the installation, while the eastern portion and several other tracts became Army land about 20 years later (Figure 3-1). Within limits, there are no accurate records of the uses to which these lands were put prior to the 1960s.

3.1 Land Use History

The absence of a military use record means that the SEMP researchers must speculate about past events that may have shaped the condition of the lands within the study sites. Further, military use may not have been the primary force in shaping many of the sites. There is a history of roughly 100 to 150 years of European settler use of these lands, which, in many locations within the present boundaries of Fort Benning, was preceded by approximately 200+ years of intensive use by Native Americans. Thus, many of these lands have not been "natural" for centuries before Army use.

To assist SEMP researchers to understand at least some of the historical land usage at Fort Benning, a survey was made by the U.S. Army Topographic Engineering Center (TEC) of available coverage of photography. It was determined that photo coverage was available from 1938, 1944, 1957, and several later years. The 1938 coverage was acquired, but its quality was too poor to create a mosaic that could be accurately georeferenced. After consultation with the SEMP research team, the 1944 coverage was selected as the earliest good-quality complete coverage. Through FY03, the TEC scientists developed full-installation coverage of Fort Benning (Figure 3-2), and were able to interpret vegetation patterns on that portion of the installation most heavily used by the SEMP research teams. An example of that coverage and the interpretation is shown in Figure 3-3.

In this interpretation, the TEC used a classification expanding slightly on standard minimum vegetation classification. The term "Forest" (F prefixes) is used to identify areas where the stems of the trees are more or less continuous, while "Woodland" (W prefixes) is used for areas where there is woody vegetation, but where the spacing is so great that what one sees are only scattered trees. Each of these groups is further divided into Pine, Deciduous, and Mixed classes.

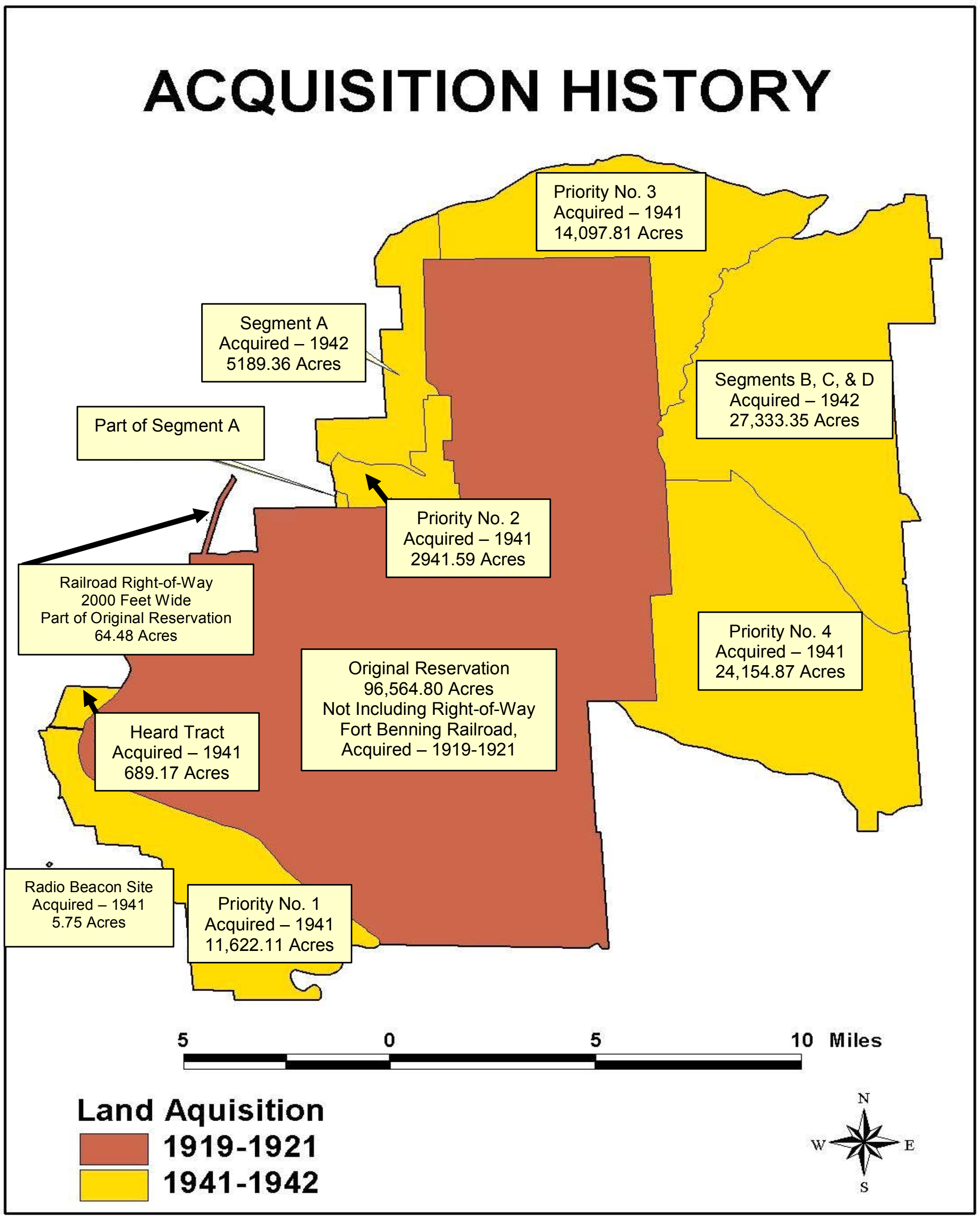

Figure 3-1. Phases of Fort Benning land acquisition.

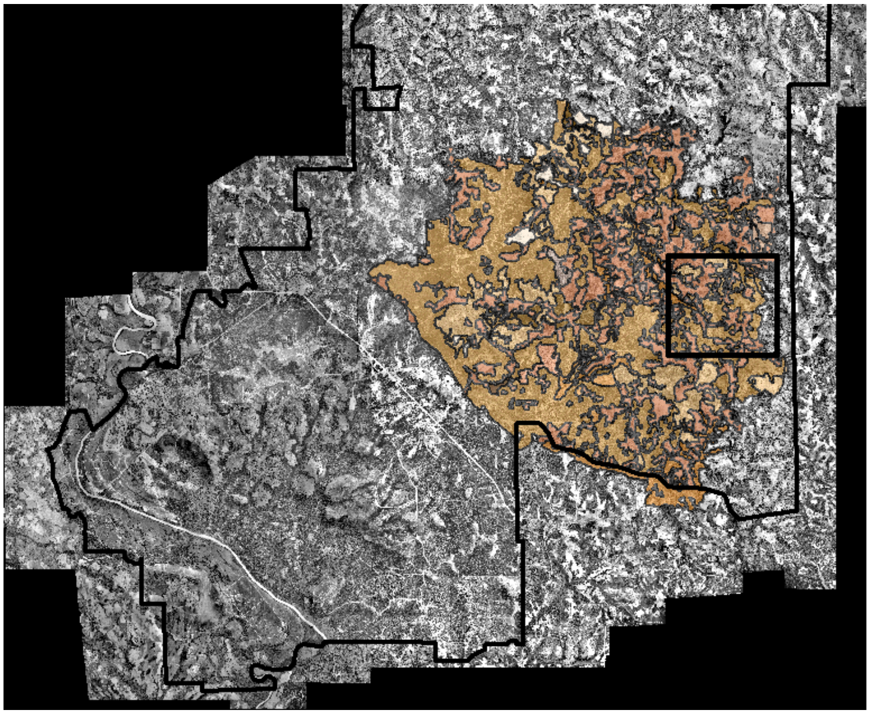

Figure 3-2. 1944 Photomosaic coverage of Fort Benning, with photointerpretation of vegetation in the primary SEMP study area highlighted.
Box shows area enlarged for Figure 3-3 (work performed by ERDC-TEC).

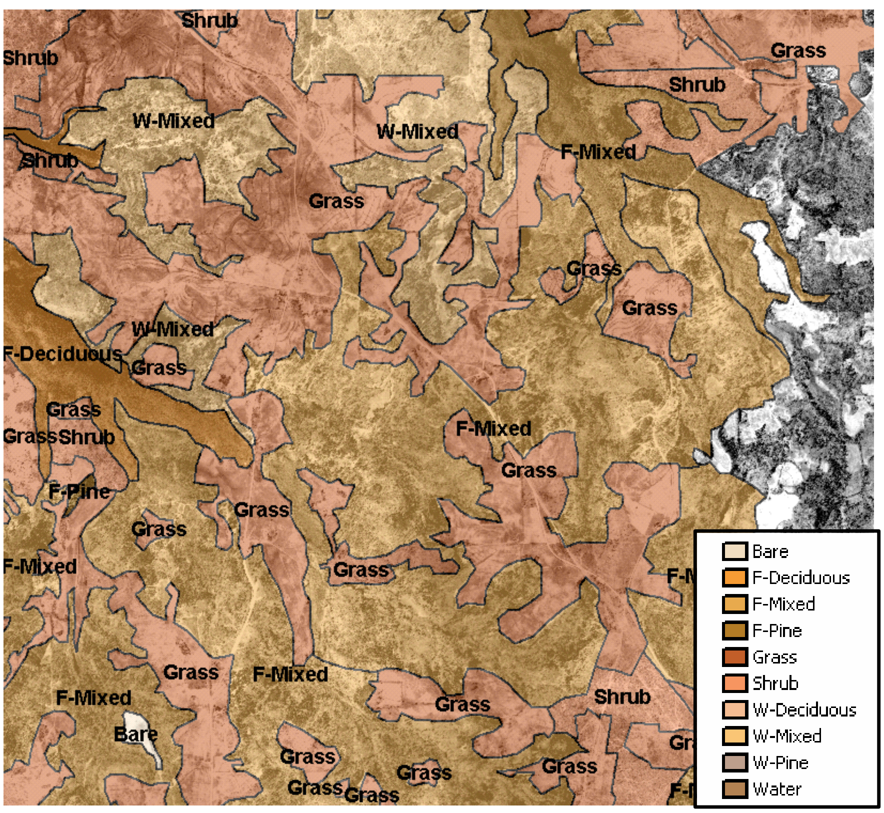

Figure 3-3. Vegetation cover interpretations emphasizing SEMP study sites from 1944 Photomosaic (interpretations by ERDC-TEC).
(Enlarged view of area in box as shown in Figure 3-2.)

The photomosaic has been made available to the SEMP research team, Fort Benning Environmental Management Division (EMD) staff, and the SEMP data repository. The SEMP teams are now able to compare the vegetation and land use in the vicinity of their study sites from 60 years in the past. With additional coverage already available from the 30- to 40-year time frame from other sources, it is possible to develop a fairly good view of human influences on the study sites for more than half a century. We note that, in a coordinated effort, the Fort Benning EMD funded the TEC study team to prepare photomosaic coverage, from the same series of 1944 photography, which extends this layer 2 miles beyond the installation's boundaries. Fort Benning thus has available a basis from 60 years ago to examine both military-influenced and natural changes in vegetation and land use. This is of significant potential value in providing a basis for long range plans, such as are proposed in the installation's integrated natural resources management plan (INRMP).

3.2 Climatic Analysis

When one is studying any natural phenomenon, there is always some question as to whether or not the data observed are "typical" of that species/site/region. This became of particular concern in the SEMP studies. During the 1999 and 2000 research seasons, a significant drought occurred. During the 2001 research season, a moderate drought occurred. At its worst, no water flowed in 9 out of 10 streams where SEMP water quality instruments had been installed. Since unusually dry seasons occurred during two of the three data collecting opportunities, the SERDP Science Advisory Board (SAB), in 2001, raised the question, "Are the data being collected representative of the local ecosystem?" A project designed to answer this question was budgeted in FY02 and initiated in October 2002. All information following is based on the ERDC-CERL Technical Note 04-1, *SEMP Historical Meteorology Evaluation for the Area Near Fort Benning, GA: 1999 – 2001*, by Robert C. Lozar.

The objectives of this study were to determine how aberrant the weather (temperature, precipitation, and stream flow) was during the first three SEMP data collection seasons (1999-2001 – the Study Years) and to suggest the possible effect that using the data from these years might have on the validity of SEMP-developed ecosystem models that propose to use the Study Years data as validation. In summary, the results of this study were as follows.

3.3 Temperature

A review of Regional Climatic Data Center records for the west-central section of Georgia for temperature for the period beginning in 1895 and continuing to 2003 (Figure 3-4) shows, for the study years, the average monthly temperatures were 50.5, 51.0, and 52.3 °F. These temperatures are 3.4, 3.9, and 5.2 degrees above the long-term average of 47.1 °F. These values are significantly above the average, showing a 3-year trend higher with the last 2 years above the first Root Mean Square (RMS) of the average temperature. They also may represent a portion of a larger trend (lasting 10 years) of above average temperatures that began roughly in the middle to late 1980s and has continued at the higher level since then. The Study Years are also unusual in that their averages were noticeably above the 10-year moving average (roughly 49.5 °F by +0.9, +1.4, and +1.7 degrees for 1999, 2000, and 2001, respectively). Therefore, all 3 years can be characterized as warm in a warm period. Following further along this line of thought, times of warmer and colder weather have occurred in lengths of roughly 16.5 years.

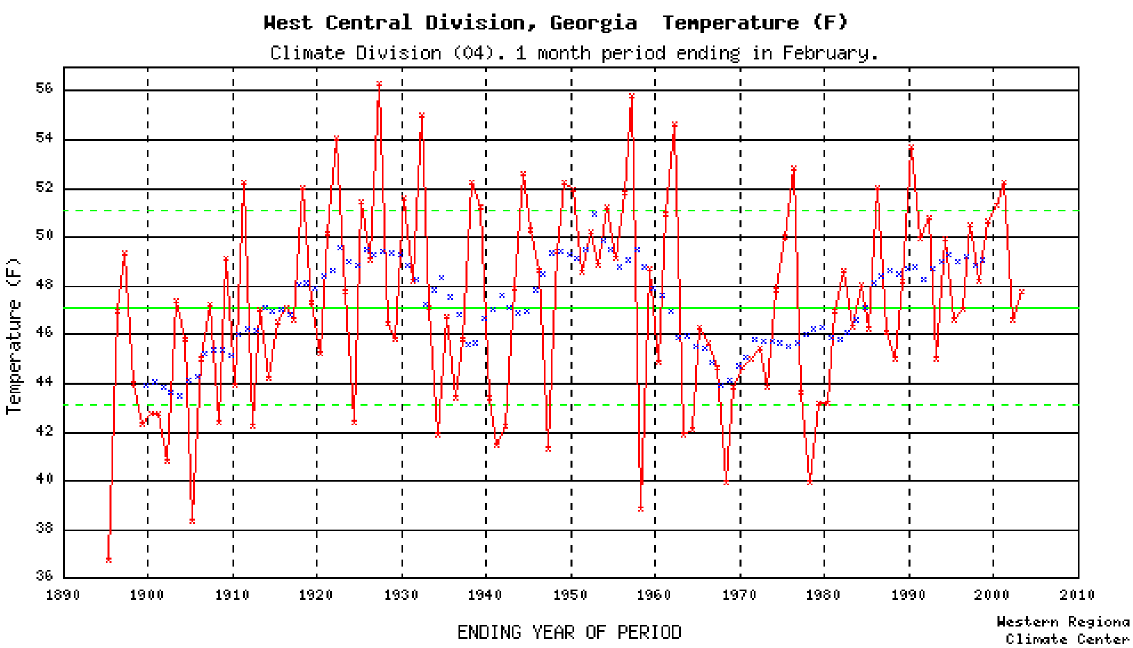

Figure 3-4. Temperature for the west-central section of Georgia.

Red - 1-month period, blue - 10 year running mean, green - average (solid), ± sigma (dashed).

Average Temperature	1-Month Period Ending in Month 2
YEARS:	1890 - 2010
AVERAGE	47.121
SIGMA (RMS)	3.991
COEFF OF VAR	0.085
SKEWNESS	-0.060
MEDIAN	47.000
MAXIMUM VALUE	56.300
MINIMUM VALUE	36.700
NUMBER OBS	109.

3.4 Precipitation

Precipitation is another major climatic concern, and, in addition to being warmer, local perception is that these years were very dry, especially at critical periods. Climatic data center records similar to those for temperature, and covering the same region (Figure 3-5), show rainfall of 38.6, 38.8, and 42.9 inches for 1999, 2000, 2001, respectively. The average of data for all the years of record is 50.1 inches with an RMS of 7.5 inches. Thus, the Study Years 1999 and 2000 were much drier than average, the driest since 1954 when the last major drought in Georgia is recognized. The year 2001 is also classed as a dry year. The years immediately preceding our Study Years tended to be wetter than usual, so the contrast in the impressions of local individuals might be enhanced. The Study Years are not astoundingly unusual; single drought years of about 1 RMS have occurred 20 times previously. Significantly more extreme events have occurred in 1954 (dry) and 1929 (wet). In addition, three noteworthy drought years in a row (1895 to 1897) have occurred previously. Of these three, one year was greater than the RMS value and two years near the RMS value. This suggests that even extended drought is within a normal pattern.

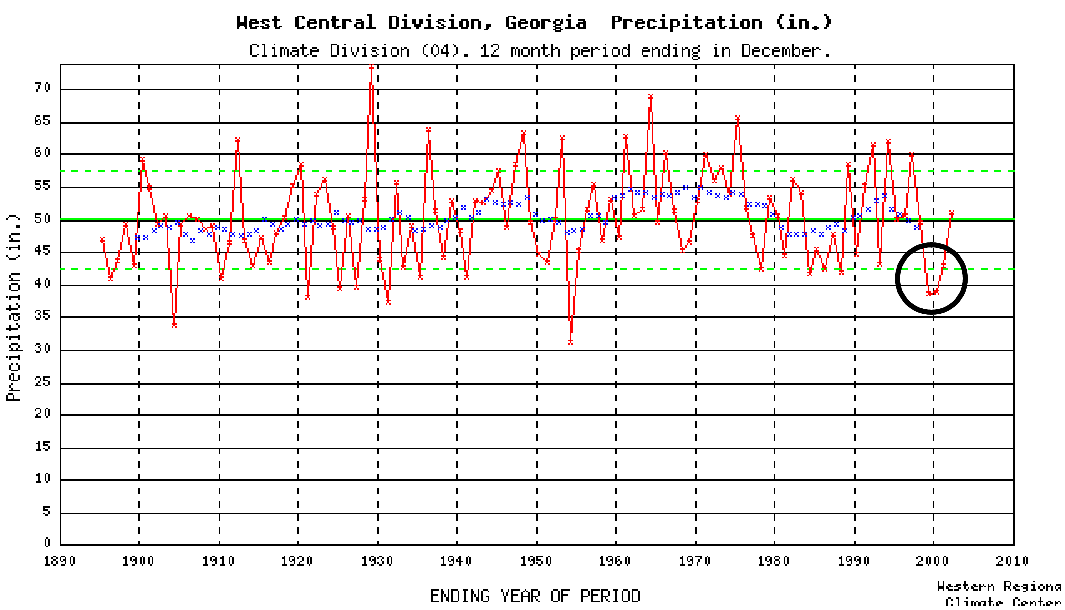

Figure 3-5. Precipitation for the west-central section of Georgia.

The three Study Years appear to represent the drought portion of normal variation (i.e., it reaches, but does not significantly exceed, normal extremes). Ecosystems respond to forcing agents. A drought as a forcing agent is similar to forest fire as a forcing agent. In both cases, although they occur infrequently, they are nevertheless integral to the definition of an ecosystem. Researchers may actually consider themselves fortunate to have captured within their data one of the important events of the region's ecology. Similarly, the low stream flow rates observed (a reflection of low precipitation) are also ecosystem forcing events that help to define the limits of what a system can endure and how the system sustains itself.

3.5 Streamflow

One significant result of decreased precipitation is the effect on streamflow. The study examined flow in the Chattahoochee River, a large river bordering Fort Benning, and in Upatoi Creek, a smaller, perennial stream that flows through the installation. Figure 3-6 shows the variation between the study years and the 70-year average for Upatoi Creek.

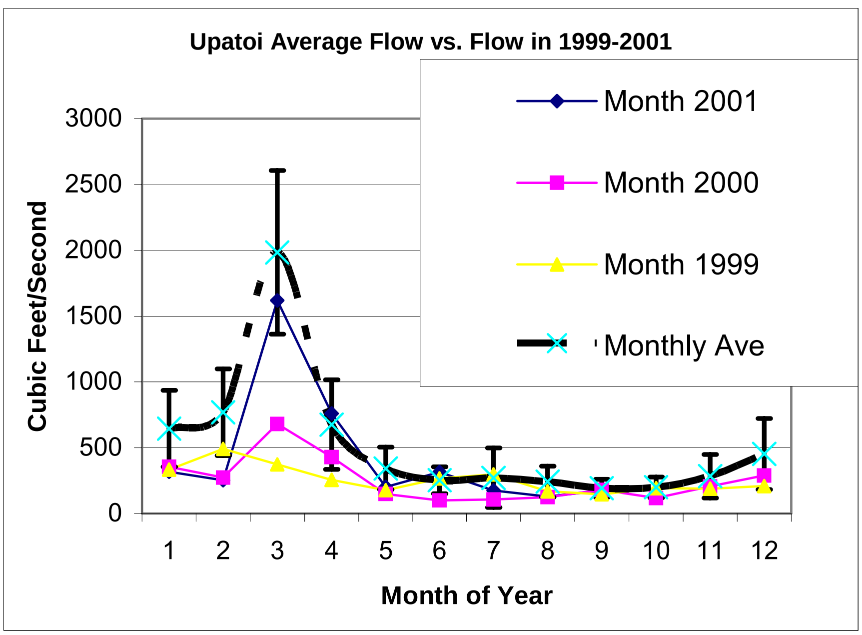

Figure 3-6. Streamflow in Upatoi Creek compared to long-term average.

The most important finding of the study with respect to streamflow appears to be that, while the low flow periods of the drought years (May-December in Figure 3-6) were not significantly lower than average, for 1999 and 2000 there was no clear "spring high flow" period in either year. Thus, many of the biological phenomena that might be associated with this period would appear to have been compromised, and recharge of soil moisture could not have been normal. From the Upatoi Creek data, flows for 2001 roughly reflect the average situation. Even in 1999 and 2000, the low flow period is not very different from normal, particularly in Upatoi Creek. For both stations, however, 1999 and 2000 flows were well below average. This is almost entirely explained by the fact that the period of high flow for 1999 and 2000 were significantly lower than even a standard deviation. For both graphs, the peak flow period for 1999 and 2000 is barely distinguishable from the average low flow. This is a critical issue, since the yearly water flow budget (the sum of the area under the curves) is determined in the February to May period. For 1999 and 2000, the water flow budget was minimal at this important period.

This study provides the following recommendations: (1) Recognize in models being developed that the data collected thus far are likely to represent the drought portion of normal variation, (2) Data to test the variation resulting from an ecosystem model cannot be represented using solely data collected during the period 1999-2001, (3) To adequately capture the full range of expected fluctuation, the period of long-term data collection should be at least 25 to 35 years.

SEMP RESEARCH REPORTS

4 Determination of Indicators of Ecological Change – 1114A

Fourth Annual Progress Report
Project Year 2002-2003 (FY03)
University of Florida – Purdue University
Researchers:
K. Ramesh Reddy, P.I., Chair, Department of Wetland Biology
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Suresh Rao, School of Civil Engineering, Purdue University
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4.1 Executive Summary

Introduction

The goal of this research is to develop indicators of ecosystem integrity and impending ecological change that include natural variation and human disturbance. We are evaluating parameters related to properties and processes in the understory vegetation, soil, and surface hydrology as potentially sensitive indicators of ecosystem integrity and ecological response to natural and anthropogenic factors. The basic premise is that soil serves as the central ecosystem component that links the quality of the terrestrial habitats (by influencing vegetation and its stability) and the aquatic habitats (via control of soil erosion and overland runoff). Our research and monitoring plan addresses the following objectives:

- Identification of physical, chemical, and biological variables of soil, surface hydrology, and vegetation that may be used as indicators of ecological change.
- Evaluation of potential ecological indicators for sensitivity, selectivity, ease of measurement, and cost effectiveness.
- Selection of indicators that (1) show a high correlation with ecosystem state, (2) provide early warning of impending change and (3) differentiate between natural ecological variation and anthropogenic negative impacts.

- Determination of the range of natural variation for indicator variables, and comparison with the range of values under anthropogenic, especially mission-related, influences.

FY00-02 Summary

In Phase 1 approximately 300 sites within 6 watersheds were categorized as low, moderate, or severe disturbance based on visual assessment of vegetation and soil disturbance in the immediate vicinity. Comparison of soil total carbon (TC) and microbial biomass carbon (MBC) from these sites supports field observations that the primary impact of intensive military training on soil quality is soil erosion in uplands and associated sedimentation in wetlands. Topsoil loss in disturbed upland sites results in decreased soil organic matter content in upland sites and concomitant deposition of silt and clay in downslope and downstream wetlands. In general, for both wetlands and uplands, soil chemical and biological parameters correlated with soil organic matter tend to decrease with increasing site disturbance. The ratio MBC:TC tends to increase with increasing soil disturbance, which may relate to the relative availability of organic carbon to heterotrophic microorganisms in the soil. It appears that the loss of soil organic matter near the soil surface through topsoil erosion in uplands or sedimentation in wetlands results in a higher proportion of freshly-deposited organic material in the soil organic matter pool, thus stimulating microbial growth.

Multivariate statistical analyses were performed on the Phase 1 soil biogeochemical data set. Cannonical Discriminant Analysis was used as to reduce the dimensionality of the multivariate data set while maximizing the separation between specific categories of data. Discriminant Function Analysis was used to classify observations into groups on the basis of the biogeochemical data set. Results indicate that canonical variable 1 provides relatively good separation among sites designated as low and moderate, while canonical variable 2 primarily provides separation of severe-disturbance sites from those with low to moderate disturbance. Results of Discriminant Function Analysis indicate that the Phase 1 soil biogeochemistry data “predict” to a large extent the degree of site disturbance.

Structural and compositional parameters of vegetation were measured at the Phase I soil biogeochemical sites. A total of 113 woody and 110 herbaceous species were encountered. Cannonical Correspondence Analysis of relative woody plant cover with environmental variables indicates a separation of low disturbance sites from moderate and severe sites, but no marked separation between moderate and severe disturbance sites. There appears to be a relationship between the percent cover of a subset of the herbaceous species and sites of severe disturbance.

Distributed soil moisture content was sampled in June and August 2001. Analysis indicated relatively dry upland soils with increasing water content on the hill slopes. The majority of the water storage is confined to the areas immediately adjacent to the stream channel. Stream flow, stage, rainfall and throughfall data collection was initiated in FY00 and expanded during FY01. Initial results of the throughfall study indicate a distinct signature among the five vegetation categories into five different groups: wetland, pine plantation, hard wood, mixed, and pine. A spatially distributed hydrological input model was developed, including a Gash throughfall model coupled to a GIS system that uses landuse coverages. A preliminary hydrologic model for the Bonham-2 subwatershed using TOPMODEL was run with reasonable results.

Soil sampling for biogeochemical analyses was continued in FY02 along disturbance gradient transects and at vegetation study sites investigating recovery from clearcutting. Multivariate data analyses were completed on Phase I and II biogeochemical data. Hyperspectral analysis was conducted on soil samples taken from Fort Benning in Phase I in order to determine whether soil sample spectral signatures can be used to discriminate ecological impact, and to determine the relationship between biogeochemistry and spectral reflectance for soil samples. The reflectance signatures of soil samples were analyzed using multivariate statistical methods. Principal Components Analysis was performed to achieve reduction of the dimensionality of data (2000+ variables of wavelengths) into a few important variables. Canonical Discrimination and Discriminant Function Analysis were conducted to determine whether spectral signatures can be used to discriminate soils taken from bottomlands and uplands and also from low, medium and highly disturbed sites. Canonical Correlation and Partial Least Squares were carried out to relate spectral signatures to soil biogeochemistry.

Discrimination on the basis of landscape position using hyperspectral data was successful using one canonical variable, and results were comparable to Cannonical Discrimination Analysis results found using biogeochemistry data directly. Cannonical Discrimination on the basis of disturbance was not as successful as that obtained using 20 biogeochemical variables, but comparable to that obtained using 4 variables. Results of the Discriminant Function Analysis for landscape position based on the reflectance data are slightly less accurate than those obtained using 18 biogeochemical variables, but provide approximately the same accuracy as those obtained using 4 biogeochemical variables. Results of the Discriminant Function Analysis for disturbance based on reflectance data are slightly less accurate than those obtained using 18 biogeochemical variables, but provide approximately the same accuracy as those obtained using 4 biogeochemical variables.

A chronosequence study focusing on recovery of groundcover vegetation after clear cutting was conducted in 2000/2001, and data analysis continued during FY02. Ground cover vegetation was assessed within two major soil groups (loamy vs. sandy soils) and four time intervals (0-3, 8-10, 18-20, and >30 years) after logging for a total of 32 sites. Identification of pattern and rate of ground cover recovery following clear cutting will aid in identification of sensitivity and return rate for herbaceous species following low to moderate levels of disturbance, and help to separate natural variation from anthropogenic disturbance. Results indicate that percent clay and sand contributed significantly to variation in vegetation, and Cannonical Correspondence Analysis produced a weak separation of species based on age classes. Increase Bulk Density was associated with sandy soil in 0-3 year post-clearcut sites, and increased overstory density was associated with 15-20 and >30 year age classes.

Soil water content measurements were obtained every 2 months during FY02 in the Bonham-1 watershed using 50-meter contour lines as references. Measurements were used to estimate the total water storage and spatial moments of water content within the catchment. When compared to volumes estimated from precipitation and hydrograph data, our estimated soil-water storage appear to account for the expected volume of precipitation minus hydrograph volume.

Watershed hydrologic monitoring activities continued during FY02, including precipitation monitoring; stream flow gaging; throughfall measurements; water content sampling; and soil water, groundwater, and stream water sampling. Hydrological sampling occurred approximately two times per month during FY02. The impact of vegetation community and dynamics on water input were characterized by the throughfall study, and results suggest that forests comprised of multiple species may require species-based corrections to model parameters. Water quality measurements revealed low levels of most nutrients, but significantly higher levels of some nutrients (TKN [Total Kjeldahl Nitrogen], sulfate, DOC [Dissolved Organic Carbon], TOC [Total Organic Carbon], NH_3 [ammonia], Cl [chloride]) were observed in throughfall and stemflow than in soil and stream waters. A seasonal increase in stream water nitrogen was observed during the winter months. This increase coincided with the decreased canopy cover in the wetland and hardwood communities. Preliminary modeling results suggest that an understanding of hydrologic pathways is necessary to link excess nitrogen to stream water chemistry. A joint effort between the University of

Florida (Jacobs) and Oak Ridge National Laboratory (Garten and Ashwood) was established to generate a distributed, regional model of excess nitrogen at Fort Benning and to develop a hydrologic modeling framework that links the nitrogen model to the stream water chemistry.

FY03 Summary

Watershed hydrologic monitoring activities continued, including precipitation monitoring; stream flow gauging; throughfall measurements; water content sampling; and soil water, groundwater, and stream water sampling. Hydrological sampling was performed approximately once per month in FY03. Runoff sampling continued on an event basis using an ISCO™ automated water sampler. Hydrologic and water quality data will be used to parameterize the Riparian Ecosystem Management Model, which was developed by the U.S. Department of Agriculture as a tool to aid natural resource agencies and others in making decisions regarding water quality management. The model simulates movement of water and sediment; dynamics of C, N, and P; and vegetation growth within the watershed. The riparian system is characterized in the model as three zones parallel to the stream, representing increasing levels of management in the direction of the uplands. Preliminary modeling results suggest that an understanding of hydrologic pathways is necessary to link excess nitrogen to stream water chemistry. These results will be correlated to soil biogeochemical parameters from transects paralleling two second-order streams in the Bonham watershed sampled in December 2002 and one sampled in June 2003. This research is part of dissertation research to be completed in 2004. Soil water content measurements in the Bonham-1 watershed obtained in FY02 are compiled in a master's thesis.[1] The chronosequence study conducted in 2000/2001 focused on recovery of ground cover vegetation after clear cut. Further analysis and completion of a master's thesis[2] (Archer 2003) from the chronosequence data was accomplished in 2003. Groundcover vegetation was assessed within two major soil groups (loamy vs. sandy soils) and four time intervals after logging, for a total of 32 sites. Military activity for these sites was low to moderate. Identification of pattern and rate of groundcover recovery following clearcutting will aid in identification of sensitivity and rate of return of herbaceous species following

[1] D. Perkins. 2003. Soil Hydrologic Characterization and Soil-water Storage Dynamics in a Forested Watershed. MS Thesis. Purdue University.

[2] Archer, J. K. 2003. Understory vegetation and soil response to silvicultural activity in a southeastern mixed pine forest: A chronosequence study. M.S. Thesis. University of Florida.

low to moderate levels of disturbance, and will further separate natural variation from variation attributed to anthropogenic disturbance.

A second sampling of riparian soils was conducted in June 2003 in support of the watershed hydrology model (Riparian Ecosystem Management Model). This sampling event was conducted to account for seasonal trends in carbon and nitrogen inputs to the watershed. Biogeochemical analyses are completed on fall 2002 samples, and analyses of most recent samples are ongoing. Results will be used to determine values for soil nutrient compartments of the hydrologic model. Sampling and analyses of litter and soil for the litter decomposition study are ongoing. A study of aggregation and soil structure as potential indicators of compaction and erosion is ongoing. Results of Phase I reflectance signatures of soil samples have been analyzed using multivariate statistical methods and results are being prepared for publication. Hyperspectral reflectance analyses of validation samples have been completed. Comparison of in situ reflectance with lab values is completed. Data analysis and manuscript preparation are underway.

General Conclusions

1. Approximately 2-15% of throughfall shows up as stream flow. Median value is approximately 6%. Time to peak discharge is approximately 3 hours.
2. Storm intensities are usually $<K_{sat}$ at most places, except severely disturbed areas.
3. Soil cover plays an important role in determining the potential runoff and may be more important than K_{sat} of surface soil.
4. Biogeochemical cycling in soils and vegetation are influenced by soil-water content.
5. Soil organic matter and its cycling is an important biogeochemical indicator.
6. Spectral analysis shows excellent promise to determine soil nutrient status.
7. Understory vegetation species composition correlates with disturbance. Clear indicators generally observed only at heavily impacted sites.
8. Nutrient and sediment loads in “low” and “medium” impact sites are not too large. Sediment may be the most important water quality attribute for “severe” impact sites.
9. Water quality measurements revealed low levels of most nutrients.
10. Decreased canopy cover in wetlands and hardwood communities of impacted areas increases the nutrient load to streams.
11. Riparian zones play an important role in determining water quality.
12. Multivariate Analysis, Principal Component Analysis, and Canonical Correspondence Analysis yielded combinations of factors that are useful in identifying impacts.

4.2 Introduction

Our research seeks to develop suitable indicators of ecosystem integrity and impending ecological change resulting from both natural variation and anthropogenic activities. We will use a multidisciplinary and multiscale approach, which will result in robust techniques for ecosystem monitoring and evaluation. Results of the study will enhance the ability to minimize, mitigate, or remove major negative environmental impacts on DoD's ability to conduct the military mission. Through the proposed research plan, we will address the SEMP objective of identifying indicators that signal ecological change in intensively and/or lightly used ecological systems on military installations. These indicators will provide early indications of change associated with (1) natural ecosystem variability and (2) military activities, including training and testing, as well as other land management practices. Early indications of change, and an understanding of the likely causes, will improve installation managers' ability to manage activities that are shown to be damaging, and prevent long-term, negative effects.

The concept of ecosystem integrity, or "health," in the context of the military installation, encompasses not only the sustainability of the "natural" biota in the system, but also the sustainability of human activities at the installation, namely the military mission. Thus, changes in ecological condition are of great concern to both resource managers and military trainers. A suite of variables is needed to measure changes in ecological condition. Two types of indicators that may be useful are (1) variables that inform managers about ecosystem status and (2) variables that signal impending change. In many cases, these indicators may be the same. Both types are needed, but variables that serve as early warnings of impending changes outside the natural range of variation, and variables that are shown to be related to activities affecting the military mission, may be especially valuable.

4.3 Technical Objectives

We will evaluate a suite of parameters related to properties and processes in the understory vegetation, soil, and surface hydrology as potentially sensitive indicators of ecosystem integrity and ecological response to natural and anthropogenic factors. In general, the soil hydrologic and biogeochemical parameters to be examined relate to changes in soil physical and chemical characteristics, and the response of soil microbial population and plant communities. To the greatest extent possible, cause and effect relationships will be developed between environmental changes, due to both natural variability and anthropogenic perturbation, and soil and vegetation responses, primarily as they relate to nutrient storage, nutrient turnover, and population dynamics.

Our basic premise is that soil serves as the central ecosystem component that links the quality of the terrestrial habitats (by influencing the vegetation and its stability) and the aquatic habitats (via control of soil erosion and overland runoff). Thus, a careful study of soil parameters and processes and linking them to impacts on terrestrial/aquatic habitats is the basis for our experimental approach. Furthermore, we aim to establish a sound scientific basis for the empirical parameters that might be used as ecological indicators.

Our proposed research and monitoring plan will address the following objectives:

- Identify physical, chemical, and biological variables (properties and processes) associated with soil, surface hydrology, and vegetation that may be used as indicators of ecological change.
- Evaluate potential ecological indicators based on sensitivity, selectivity, ease of measurement, and cost effectiveness.
- Select indicators that most effectively (1) show a high correlation with a certain state in a specific ecosystem, (2) provide early warning of impending change and (3) differentiate between natural ecological variation and anthropogenic negative impacts.
- Determine the likely range of natural variation for indicator variables, and compare with the range of values under anthropogenic, especially mission-related, influences.

4.4 Summary of Previous Results (FY00-02)

4.4.1 Soil Biogeochemistry

The Phase 1 objectives were to characterize the distributions (range, central tendency) of indicator variables at a regional scale and to determine the response of variables to impacts related to military training and other land uses and management practices. Sampling for Phase 1 of the soil biogeochemistry component was completed during FY00. FY00 sampling and monitoring was conducted within six watersheds of order 3 or 4, which had been proposed and/or selected as ECMI (Ecosystem Characterization and Monitoring) long-term monitoring units. These watersheds, associated with Sally Branch, Bonham, Halloca, Randall, Wolf, and Shell Creeks, represent a wide range of military and nonmilitary land uses and anthropogenic disturbance regimes (type and intensity of disturbance). Analysis of Phase 1 data was performed during FY01.

FY01 sampling was conducted for a comparative study of soil and vegetation-based indicators in both wetland and upland regions of highly-disturbed (D-15 compartment) and minimally-disturbed (D-4) areas. These areas were sampled both in December 2000 and August 2001 in order to examine temporal or seasonal variability in soil indicators. Soil cores were taken at 21 points along a 400-m transect in each upland site (high and low disturbance) and at 18 points along 3 transects across each wetland site. Each soil sample consisted of a composite of five 20-cm deep sub-samples taken by 1-inch diameter soil probe within a 1-m^2 quadrat. Riparian wetland transects, 80 m in length, were located on either side of the stream (paired transects) and sampled at 20-m intervals. Wetland soils were sampled to a depth of 10 cm, using a 6.5-cm diameter polycarbonate corer. Each sample represented a composite of three subsamples taken within a 1 m^2 quadrat. The transect-based sampling layout facilitates both comparison of indicator response in high and low disturbance areas and, simultaneously, an evaluation of local, within-site variability. The soil characteristics and properties evaluated for this study were total carbon (C), nitrogen (N), and phosphorus (P), pH, organic matter, exchangeable NH4+, potentially mineralizable N, microbial biomass C and N, soil respiration, Mehlich 1 and 3 extractable P, HCl and ammonium oxalate extractable P, Fe and Al, and microbial enzyme activity (acid phosphatase, beta glucosidase and dehydrogenase).

Additional soil and vegetation monitoring transects were established at four upland and three wetland sites in training compartments D12, D13 and O3 during June 2001. Upland transects were sampled in areas of high military disturbance (Rowan Hill – D12), low disturbance (D13), and planted pines (2 stands in O3 – ca. 5 years and 12 years). Wetland transects were sampled in watersheds with low (D13) and moderate military impact (D12), and a watershed dominated by managed timber land. Soils sampled along the upland and wetland transects were analyzed for total and extractable nutrients and microbial activity, as previously indicated. The upland transects, all of which are underlain by Troup loamy fine sands, were 200 m total length, and were sampled for soil biogeochemical characterization at 20-m intervals. Sampling procedures were modified slightly for wetland sites during this sampling event (i.e., the sampling depth was decreased from 10 to 5 cm). It was concluded that sampling only the upper 5 cm of wetland soils provided greater sensitivity and resolution for comparing soil biogeochemical processes among sites. To accommodate this change, the previously sampled wetland transects were resampled using a soil depth of 5 cm. Analysis was completed for soil samples during FY01-02.

Soil Biogeochemical Analyses

The 300 Phase 1 sites were categorized as low, moderate, or severe disturbance, based on visual assessment of vegetation and soil disturbance in the immediate vicinity (ca. 0.1-ha area surrounding the sampling point). Such an initial characterization, albeit a rough estimate, of site disturbance was considered a necessary component of the evaluation process for soil variables as potential indicators of ecological condition.

A summary comparison of soil TC and MBC (expressed as a proportion of total C {MBC:TC}) among low-, moderate- and severe-disturbance sites grouped by landscape position (uplands and bottomlands/wetlands) is presented in Figure 4-1. These data support field observations that the primary manifestation of intensive military training, with respect to soil quality, is soil erosion in uplands and associated sedimentation in wetlands. Loss of topsoil in disturbed upland sites has resulted in decreased soil organic matter content, shown as total C. While much of the soil organic matter lost from upland sites is apparently flushed into streams, a significant proportion of the mineral or inorganic component, primarily silt and clay, but also sand in extreme cases, tends to settle out in downslope and downstream wetlands. Thus, a decrease in organic content of disturbed wetland soils occurs as a result of “dilution” by inorganic soil material. In general, for both wetlands and uplands, soil chemical and biological parameters typically correlated with soil organic matter also tend to decrease with increasing site disturbance.

Among the soil parameters that typically decrease with increasing site disturbance is soil MBC (data not shown), which is primarily a function of decreasing soil organic matter. However, when MBC is expressed as a proportion of total soil C, the MBC:TC ratio tends to increase with increasing levels of soil disturbance. We believe that this phenomenon relates to the relative availability of organic C to heterotrophic microorganisms in the soil. It appears that the loss of “stable” soil organic matter (e.g., humus) near the soil surface through topsoil erosion in uplands or sedimentation in wetlands results in a higher proportion of freshly-deposited organic material (e.g., leaf fragments) in the soil organic matter pool, thus stimulating microbial growth within the organic material. The availability of nutrients such as N, P, or K may also be a factor, but this has not been clearly indicated by our data thus far. The relationships between soil organic matter and microbial biomass, activity, and diversity were examined in greater detail, along with implications to soil quality and ecological stability (and change), during FY02.

Phase 2 data, which is relatively site-specific compared to Phase 1 data, revealed similar trends in soil C and microbial biomass in response to site disturbance

(Figure 4-2 and Figure 4-3). Analysis of within-site spatial and temporal variability along upland and wetlands transects continued during FY02, and will be reported in subsequent reports.

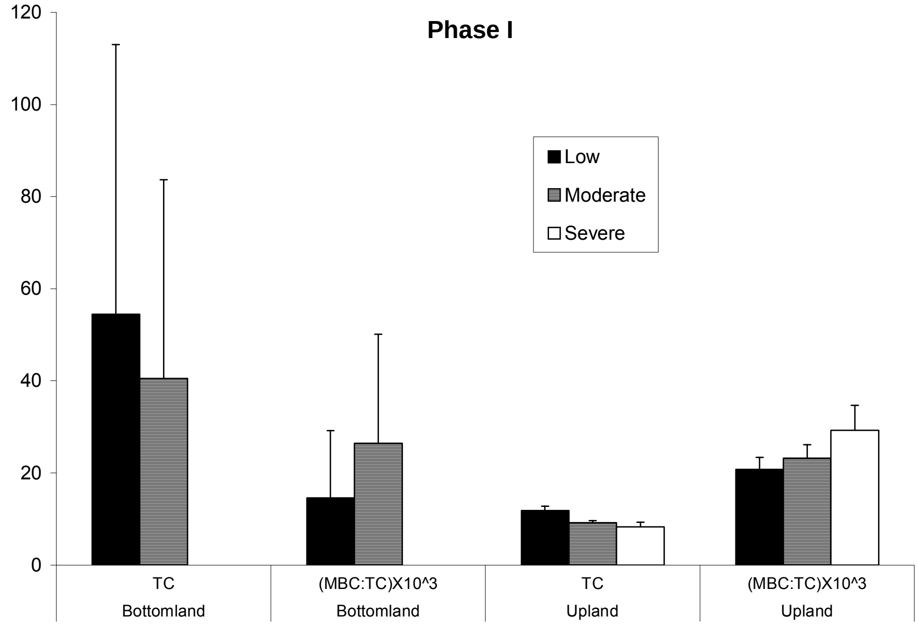

Figure 4-1. Summary of Phase 1 soil analysis (300 sites) for total carbon and microbial biomass C (as proportion of total soil C) at low-, moderate- and severe-disturbance sites in uplands and bottomlands (wetlands).
Data points are mean values, with standard deviation denoted by error bars. All wetland sites sampled during Phase 1 were classified as either "low" or "moderate" disturbance, hence there is no "severe" class shown for wetlands.

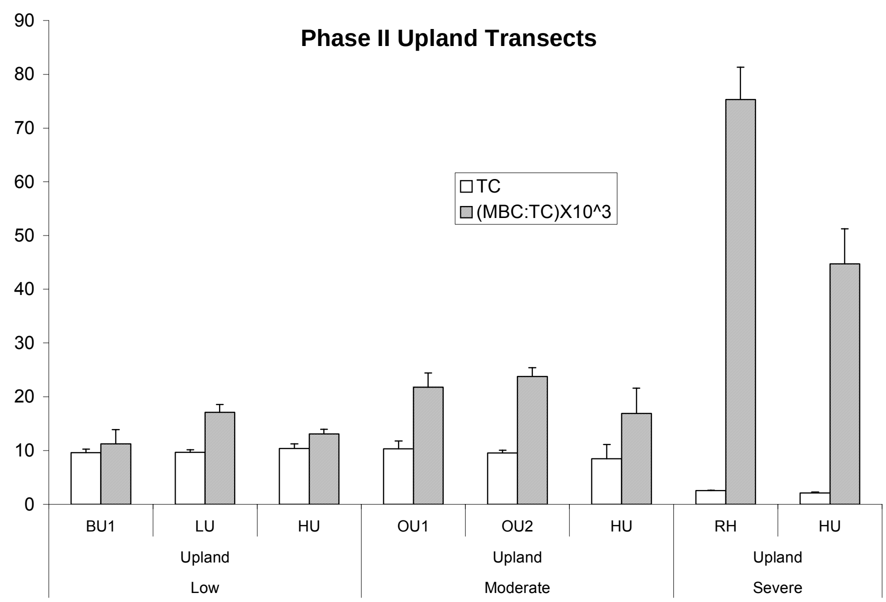

Figure 4-2. Summary of Phase 2 (transects) soil analysis for total C and microbial biomass C (proportion of total soil C) at low-, moderate- and severe-disturbance sites in uplands.
Data points are mean values, with standard deviation denoted by error bars.

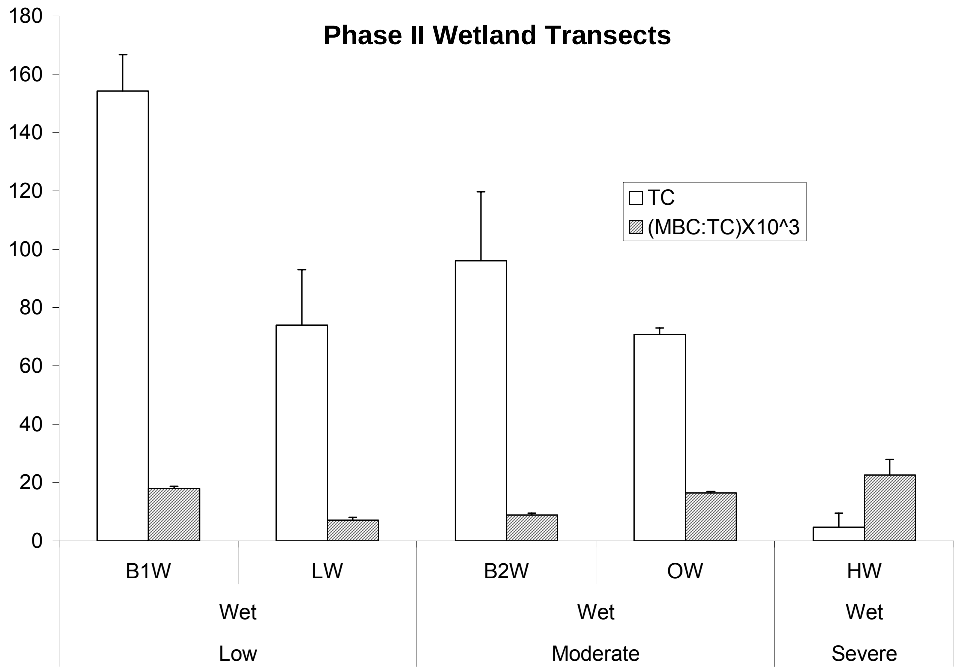

Figure 4-3. Summary of Phase 2 (transects) soil analysis for total C and microbial biomass C (proportion of total soil C) at low-, moderate- and severe-disturbance sites in wetlands. Data points are mean values, with standard deviation denoted by error bars.

In FY02, soil samples were obtained at 115 sites corresponding to the chronosequence study focusing on recovery of groundcover vegetation after tree harvest and reforestation (see Vegetation section below). In addition, sampling was repeated at wetland and upland regions previously sampled in December 2000 and August 2001 (i.e., highly-disturbed [D-15 compartment] and minimally-disturbed [D-4] areas). These areas were sampled to continue study of the temporal variability in soil indicators. Soil analyses were completed in FY02 and data analysis is ongoing.

During 2001-2002 hyperspectral analysis was conducted on soil samples taken from the Fort Benning Installation in Phase I (FY00). The objectives of the spectral analyses were to (1) determine whether soil sample spectral signatures can be used to discriminate ecological impact at the Fort Benning installation, and (2) determine the relationship between biogeochemistry and spectral reflectance for soil samples taken from the Fort Benning installation. Hyperspectral scanning of 600+ soil samples was conducted in the lab using an ASD Spectrometer. Reflectance signatures of each soil sample were taken at a 1-nm sampling interval covering the range between 350 to 2500 nm. The reflectance signatures of the soil samples were analyzed using multivariate statistical methods. Principal Components Analysis was performed to achieve reduction of the dimensionality of data (2000+ variables of wavelengths) into a few important variables. Canonical Discrimination and Discriminant Function Analysis were conducted to determine whether spectral signatures can be used to discriminate soils taken from bottomlands and uplands and also from low, medium, and highly disturbed sites. Canonical Correlation and Partial Least Squares were carried out to relate spectral signatures to soil biogeochemistry.

Multivariate analyses

Multivariate statistical analyses were performed on the Phase 1 soil biogeochemical data set, using the most-commonly analyzed parameters: pH, organic matter content, total phosphorus, water extractable P, oxalate extractable P, Mehlich-1 P, microbial P, total carbon, total nitrogen, water extractable C, microbial C, exchangeable ammonium, microbial N, Mehlich-1 Fe, Al, Ca, Mg, and K, oxalate extractable Fe and Al. All parameters except for pH were log-transformed prior to analysis, due to the log-normal distributions of these variables.

Cannonical Discriminant Analysis was used as a visualization technique to reduce the dimensionality of the multivariate data set while maximizing the separation between specific categories of data. This was accomplished by developing a smaller set of cannonical variables (which are a weighted linear sum of the original variables), that preserve the maximum variability of the original data set that can be attributed particular data classes. For the Phase 1 soil biogeochemistry data set, Cannonical Discriminant Analysis was conducted to provide maximum discrimination among predetermined site disturbance classes (low, moderate, and severe). Results in Figure 4-4 show that the canonical variable 1 provides relatively good separation among sites designated as low and moderate, while canonical variable 2 primarily provides separation of severe-disturbance sites from those with low to moderate disturbance. Thus, canonical variable 1 represents a simple combination of soil biogeochemical characteristics that may provide a useful indicator of ecological change, especially where differences or changes in site condition are not easily discernable by observation.

Discriminant Function Analysis is a procedure for classifying observations into two or more groups on the basis of one or more quantitative measurements. To develop the discriminant function, prior knowledge of the classes from which each observation is taken is required, unlike cluster analysis. Quadratic discriminant function analysis was conducted on the Phase 1 soil biogeochemistry data set. The degree to which the a priori site disturbance classification is supported by the soils data is shown in Table 4-1 as the proportion of the sites assigned to each disturbance class (low, moderate, and severe) that fall into the assigned class, based on discriminant function analysis, as compared to the other two disturbance classes. Results indicate that the Phase 1 soil biogeochemistry data "predict," to a large extent the degree of site disturbance.

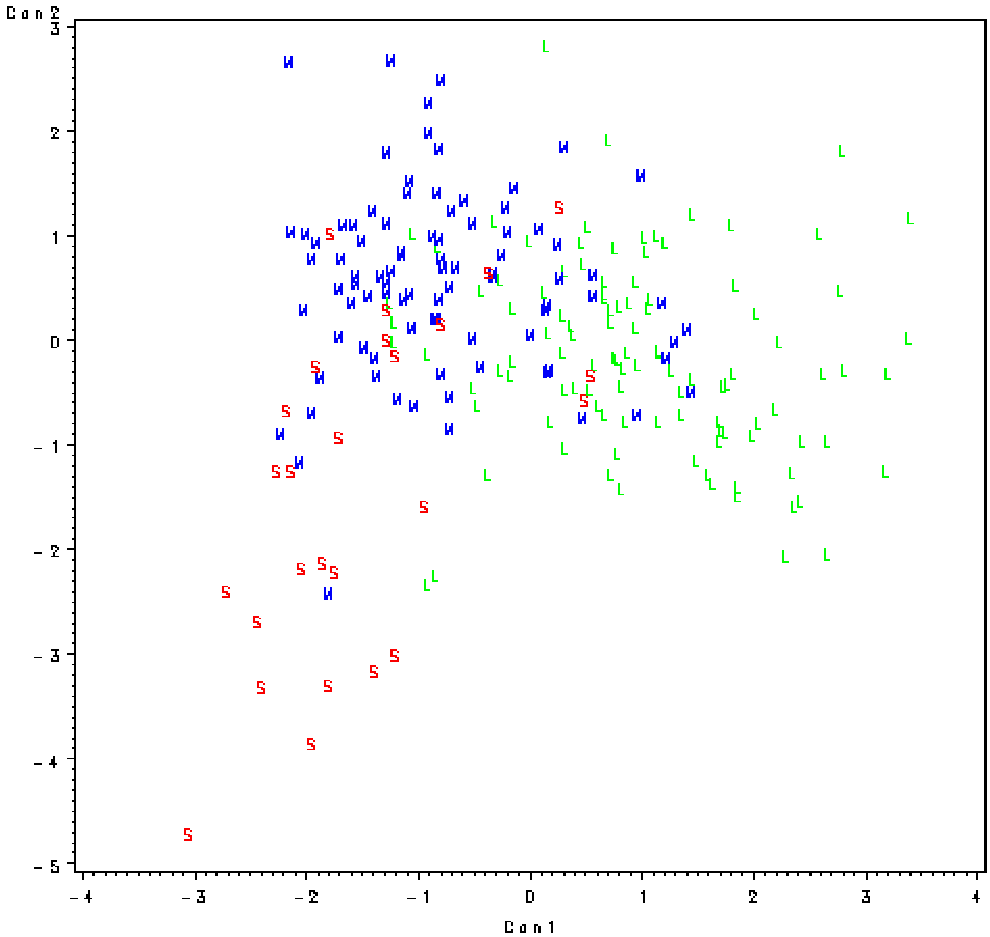

Figure 4-4. Plot of canonical variables 1 vs 2 for Phase 1 soil biogeochemical parameters. Data are grouped by level of site disturbance, based on visual assessment in the field: low (L), moderate (M), and severe (S).

Table 4-1. Results of discriminant function analysis of Phase 1 soil biogeochemistry data.

From	Low	Moderate	Severe	Total
Disturbance				
Low	89	16	3	108
Moderate	15	68	5	88
Severe	2	11	13	26
Values in "low," "moderate," and "severe" columns indicate frequency of statistical grouping of sites in each class, for each pre-determined disturbance group (rows).				

Hyperspectral Analyses

Using Principal Component Analysis, the 2000+ variables (wavelengths) were reduced to 7 principal components that explained 99.7% of the variation in the dataset (see Table 4-2). The 7 principal components were then used to perform a canonical discrimination analysis based on the disturbance type (low, medium, and high) and landscape position (uplands and bottomlands). Discrimination on the basis of landscape position was successful using one canonical variable. Results were comparable to Cannonical Discrimination Analysis results found using biogeochemistry data directly.

Table 4-2. Principal Components Analysis results.

	Eigen Value	Proportion	Cumulative
1	1608.52	0.7478	0.7478
2	287.03	0.1334	0.8812
3	174.24	0.0810	0.9623
4	44.52	0.0207	0.9830
5	17.37	0.0081	0.9910
6	9.76	0.0045	0.9956
7	3.47	0.0016	0.9972

Cannonical Discrimination on the basis on disturbance was found to be adequate using two canonical variables. This discrimination was not as successful as that obtained using 20 biogeochemical variables, but comparable to that obtained using 4 variables.

Results of the Discriminant Function Analysis for landscape position based on the reflectance data are summarized in Table 4-3. These results are slightly less accurate than those obtained using 18 biogeochemical variables, but provide approximately the same accuracy as those obtained using 4 biogeochemical variables. Results of the Discriminant Function Analysis for disturbance based on reflectance data are summarized in Table 4-4. This table again shows that the results based on reflectance are slightly less accurate than those obtained using 18 biogeochemical variables, but provide approximately the same accuracy as those obtained using 4 biogeochemical variables.

Table 4-3. Discriminant Function Analysis for landscape position based on reflectance.

From Landscape Position	Bottomlands	Uplands	Total
Bottomlands	96 (74.4%)	33 (25.28%)	129 (100.0%)
Uplands	22 (8.21%)	246 (91.79%)	268 (100.0%)
Total	118	279	397
• Analogous results using 18 soil biogeochemical variables were 94% and 98%, respectively • Analogous results using 4 soil biogeochemical variables were 82% and 91%, respectively			

Table 4-4. Discriminant Function Analysis for disturbance based on reflectance.

From Dist	Low	Medium	Severe	Total
Low	101 (55.4%)	58 (31.8%)	23 (12.6%)	182 (100.0%)
Medium	23 (13.2%)	119 (68.7%)	31 (17.9%)	173 (100.0%)
Severe	2 (4.7%)	21 (50.0%)	19 (45.24%)	42 (100.0%)
Total	126	198	73	397

- Analogous results for 18 biogeochemical variables were 72%, 90%, 10%.
- Analogous results for 4 biogeochemical variables were 43%, 90%, and 31%, respectively
- Misclassification rate related to continuity and overlap between disturbance classes

Partial Least Squares Analyses was used to develop predictive relationships between spectral reflectance and soil biogeochemistry. Phase 1 data were used to develop the relationships, and Phase 2 data were used for validation. Table 4-5 and Table 4-6 summarize the accuracy of the relationships obtained. Good Phase 1 relationships were identified for TC, TN, TP, Meh Mg, Meh K, and Meh Ca. Good Phase 2 relationships were validated for TC, TN, TP, and Meh K.

Table 4-5. Statistics for Partial Least Squares predicted values for Phase 1 sites.

Factor	Mean Error	RMS	Forecasting Efficiency
pH	0.045	0.497	0.157
Ash	0.007	0.047	0.242
Total Carbon	0.003	0.152	0.810
Total Phosphorus	0.004	0.159	0.691
Total Nitrogen	-0.01	0.180	0.795
Oxalate Al	-0.01	0.134	0.603
Oxalate Iron	0.048	0.315	0.616
Oxalate Phosphorus	-0.19	0.283	0.478
Mehlich Al	0.0	0.165	0.699
Mehlich Iron	0.004	0.290	0.575
Mehlich Phosphorus	-0.04	0.319	-0.044
Mehlich Mg	-0.00	0.306	0.782
Mehlich Potassium	-0.01	0.206	0.731
Mehlich Calcium	0.01	0.360	0.669
Microbial Carbon	-0.06	0.326	0.269
Microbial Nitrogen	-0.02	0.25	0.464
Microbial Phosphorus	-0.06	0.434	0.188
Water Ext. Carbon	-0.05	0.383	-0.07
Water Ext. Phosphorus	-0.01	0.47	-0.08
KCl Ext. NH_4	0.03	0.01	0.131

Table 4-6. Statistics for Partial Least Squares predicted values Phase 2 sites.

Factor	Mean Error	RMS	Forecasting Efficiency
pH	0.1974	0.5375	-0.385
Ash	0.039	0.445	-0.322
Total Carbon	0.022	0.234	0.841
Total Phosphorus	0.036	0.200	0.936
Total Nitrogen	0.022	.0234	0.976
Oxalate Al	0.058	0.197	-0.064
Oxalate Iron	0.004	0.372	0.448
Oxalate Phosphorus	0.041	0.352	0.352
Mehlich Al	-0.404	0.601	-0.070
Mehlich Iron	-0.304	0.524	0.245
Mehlich Phosphorus	-0.387	0.593	-0.352
Mehlich Mg	-0.473	0.781	-0.141
Mehlich Potassium	0.056	0.366	0.897
Mehlich Ca	0.108	0.432	-0.510
Microbial Carbon	-0.091	0.303	0.499
Water Ext. Carbon	-0.319	0.556	-0.153
Water Ext. Phosphorus	-0.305	0.759	-0.201
KCl Ext. NH_4	0.074	0.391	-0.919

Soil microbial diversity

The compositions and structures of methanotrophic bacteria were evaluated as indicators of impact along transects taken from uplands and wetlands. The primary tool used to compare the compositions of these assemblages is terminal restriction fragment polymorphism analysis (T-RFLP), a method to fingerprint the 16S rRNA gene belonging to methanotrophs. This method allows visualization of different genotypes of methanotrophs as peaks in an electropherogram, similar to different analytes being visualized as different peaks in a gas chromatogram. Most T-RFLP data are simply analyzed by comparing the presence or absence of a peak (or genotype) between samples. We attempted to extend the meaning of T-RFLP data by including the relative peak sizes as representative of the relative concentrations of the different genotypes in different samples. The validity of this assumption was checked in studies conducted early in 2001.

Most of the activity during the last quarter (of 2001) was to analyze data by various analytical and statistical approaches to determine the most appropriate indicators. Comparison of Shannon diversity indices for high and low impact soils indicated significantly higher methanotroph T-RFLP diversity for low impact upland than high impact uplands Table 4-7. Impact of various types is generally thought to decrease biological diversity. No significant difference was observed in diversity between high and low impact wetland samples, however.

Table 4-7. Shannon diversity indices of four different transects.

	Wetland	Upland
High impact	0.40	0.23
Low impact	0.48	0.54*
* Significantly different (P < 0.05)		

Principal Components Analysis (PCA) (Figure 4-5) did not discriminate between high and low impact samples (Figure 4-5A); however, low impact wetland samples clustered together, as did high impact wetland samples (Figure 4-5B).

In summary, a combination of statistical methods was necessary to identify differences between low and high impact regions of wetland and upland sites. A simple comparison of diversity indices discriminated between high and low impact uplands, whereas PCA was required to differentiate wetland samples on the basis of impact.

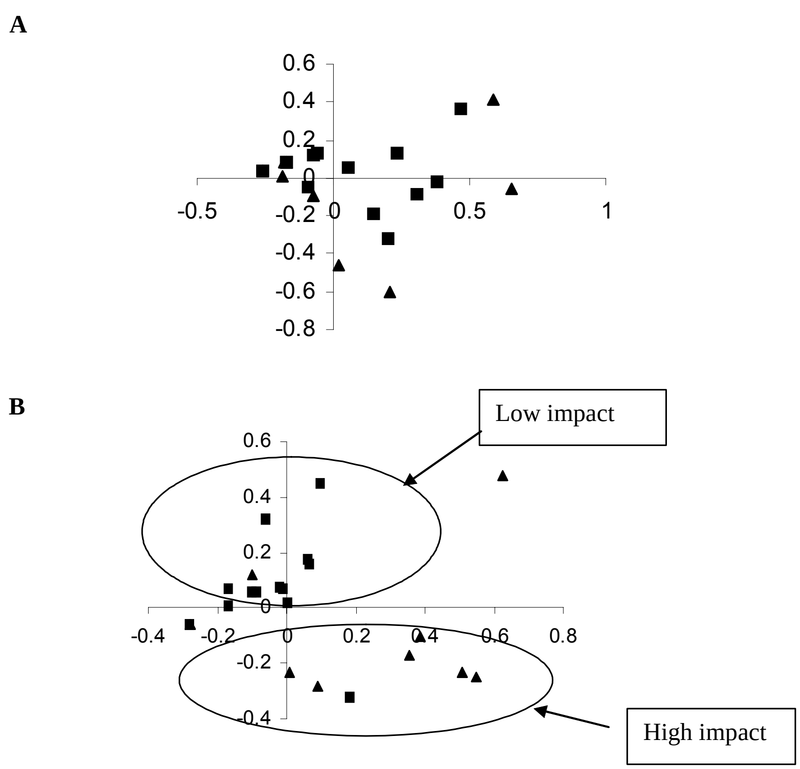

Figure 4-5. PCA discrimination of four soils based on methanotroph assemblage composition. A = upland samples; B = wetland samples. Close square (■) = low impact sample; close triangle (▲) = high impact samples. X-axis PCI, Y-axis, PCII.

4.4.2 Vegetation

Structural and compositional parameters of the vegetation were measured in the summer and fall of 2000 at the same sampling sites as selected for soil biogeochemical characterization across second and third order watersheds within six watersheds: Halloca, Randall, Sally Branch, Bonham, Shell, and Wolf Creek. Understory woody plants canopy cover (< 2-m tall) along three 5-m transects and overstory canopy cover (densiometer) were measured at all locations (n = 273). Understory composition and cover and biomass, including litter were measured within three 1-m^2 areas at the triplicate soil testing sites within the watersheds (n = 56).

Various environmental parameters were measured at all sites by the soil characterization team including: site position (upland, slope, or bottom), soil texture (sand, loam, sand/loam, clay, sand/clay, or organic), and disturbance (low, moderate, or severe). However, very few bottom sampling points had severe disturbance; most moderately and severely disturbed sites were at slope and upland positions. Disturbances resulted from both military training and logging activities.

A total of 113 woody species were encountered in the field; a small portion of these could not be identified to species, so they were given a number until definite identification can be obtained (Table 4-8). Correspondence Analysis of relative woody plant cover with environmental variables indicates a separation of low disturbance sites from moderate and severe sites, but no marked separation between moderate and severe disturbance sites. Severe disturbance was most closely associated with upland, sandy clay soils. Increased overstory canopy cover as estimated by densiometer measurements were associated with low disturbance sites. These associations have some statistical strength given the significance of the first eigenvalue (Table 4-9); however, the lack of a major decrease of the sequential eigenvalues from Axis 1 through Axis 4 indicates a lack of close association among the variables.

Severe disturbance sites were areas of active heavy military equipment training (tanks and Bradley personnel carriers). Within this classification there was a gradient of disturbance from a condition of virtual absence of woody plants to a condition of scattered larger trees (*Pinus palustris, Quercus arkansana, Pinus taeda*) and remnant shrubs and vines that could withstand, or be spread by, repeated vehicular trampling (*Opuntia* sp., *Ipomea* sp., *Vaccinium* sp., *Viburnum rufidulum*, *Crataegus* sp.). Relative cover of *Rubus* sp. and *Rhus copallina* may be an important indicator of a shift from Moderate to Severe conditions. These two species are prolific seed producers, enhancing their ability to colonize disturbed sites, and they appear to withstand physical disturbance once established.

Table 4-8. Woody species encountered in Phase I.

Scientific Name	Scientific Name
Fagus grandifolia	*Quercus marilandica*
Callicarpa americana	*Quercus velutina*
Illicium floridanum (or *parviflorum)*	*Quercus hemisphaerica*
Aralia spirosa	*Quercus laurifolia*
Aronia arbutifolia	*Quercus margaretta*
Fraxinus pennsylvanica	*Quercus stellata*
Rhododendron sp.	*Quercus sp*
Carpinus caroliniana	*Quercus falcata*
Prunus serotina	*Quercus laevis*
Nyssa sylvatica	*Quercus nigra*
Cephalanthus	*Quercus alba*
Catalpa bignonioides	*Cercis canadensis*
Quercus muehlenbergeii	*Acer rubrum*
Clethra alnifolia	*Cyrilla racemiflora*
Coralbeads	*Rhus copallina*
Crataegus sp.	*Symplocos tinctoria*
Cudwigia glandulosa	*Betula nigra*
Cyrilla racemiflora	*Rosa carolina*
Decumaria barbara	*Rubus sp.*
Desmodium sp.	*Sabal sp.*
Cornus florida	*Sassafras albidum*
Gaylussacia dumosa	*Magnolia virginiana*
Gaylussacia frondosa	*Sebastiania fruticosa*
Carya sp.	Shrub 10
Ostrya virginiana	Shrub 11
Lonicera sempervirens or japonica	Shrub 15
Hypericum hypericoides	Shrub 2
Hydrangea quercifolia	Shrub seedling
Ilex coriacea	*Smilax sp.*
Ilex decidua	*Styrax americanum*
Ilex glabra	*Styrax grandiflorium*
Ilex opaca	*Celtis*
Ipomea sp.	*Liquidambar styraciflua*
Itea virginica	Tree 3
Pueraria lobata	Tree 6
Ligustrum sinense	*Campsis radicans*
Lonicera japonica	Tree seedling
Lyonia sp.	*Liriodendron tulipifera*
Magnolia grandiflora	Unknown 2
Myrica cerifera	Unknown 8
Myrica heterophylla	*Ilex sp.*
Myrica sp.	Unknown seedling
Quercus incana	Unknown tree
Opuntia sp.	Unknown tree 1

Scientific Name	Scientific Name
Oxydendrum arboreum	*Vaccinium arborum*
Asimina parviflora	*Vaccinium sp.*
Persea borbonia	*Vaccinium elliotii*
Diospyros virginiana	*Vaccinium myrsinites*
Ampelopsis arborea	*Vaccinium stamineum*
Pinus palustris	*Viburnum rufidulum*
Pinus taeda	*Parthenocissus quinquefolia*
Pinus echinata	Vine 3
Toxicodendron radicans	*Vitus rotundifolia*
Toxicodendron pubescens	*Ulmus alata*
Prunus angustifolia	*Hamamelis virginiana*
Prunus umbellata	*Gelsemium sempervirens*
Quercus arkansana	*Yucca filamentosa*

Table 4-9. Phase I Canonical Correlation Analysis eigenvalues for woody plant species relative cover correlated with environmental variables at all sites and herbaceous species absolute cover correlated with environmental variables at upland and slope sites.

	Axis 1[a]	Axis 2	Axis 3	Axis 4
Woody sp	0.52*	0.21	0.18	0.16
Herbaceous sp	0.56 (ns)	0.48	0.34	0.28
[a] Test of significance of first eigenvalue; *= <0.05; ns= not significant.				

We did not sample many bottom sites that had had severe disturbance. The few sites of such classification, however, were downstream and close to road crossings. Erosional fans were evident along with some mortality of overstory trees. Consequently, most bottom sites were classified as low disturbance. Organic soils were rare and were at sites of impounded water (i.e., beaver ponds). It is possible that beaver ponds should be classified as Sev disturbance sites from an ecological viewpoint.

A total of 110 herbaceous species were encountered while sampling (Table 4-10). Some of these species were not identifiable to species due to immaturity, thus they were given a number. Hopefully, we will be able to identify them to species once we find them in flower and fruit. Given that a very limited number of herbaceous species were encountered within the bottom sites, CCA (Canonical Correspondence Analysis) between species cover and environmental variables was conducted for just the slope and upland sites where the vast majority of species occurred. Correspondence Analysis indicates the obvious separation of severe disturbance from moderate and low levels of disturbance along a gradient from high litter cover (Low and Moderate) to an absence of litter cover (Severe). The separation between Low and Moderate disturbance categories, however, was not distinctive; hence a possible explanation for a lack of statistical significance for the first eigenvalue of the analysis (Table 4-9). Inspection of the minimal degree of difference among the third and fourth eigenvalues also indicates a general a lack of structure among the relationships. Therefore, this analysis should be viewed as an indication of a possible trend among the variables. This result possibly is related to the relatively low sample size of the analysis (n = 36).

Litter cover varies with short-term forest management regimens (e.g., burning schedules). Litter cover will be related to basal area of overstory trees and basal area and density of understory plants, both woody and herbaceous.

Given the limitations of the weak statistical strength of the analysis, there appears to be a relationship between the cover of a subset of the herbaceous species and sites of severe disturbance. Those herbaceous species most closely associated with severely disturbed sites were: *Digitaria ciliaris, Diodia teres, Stylosanthes biflora*, Grass 4, *Aristida purpurescens, Opuntia humifusa, Haplopappus dirasicatus*, and *Paspalum notatum*. Solid stands of *Paspalum notatum* occurred on sites that had been severely disturbed in the past; this species probably was planted to reduce erosion from the sites.

Table 4-10. Herbaceous species encountered in Phase I.

Scientific Name	Scientific Name
Agalinas tencifolia	*Haplopappus dirasicatus*
Andropogon sp. (cover)	*Hexastylis arifolia (Asarum arifolium)*
Andropogon sp. (density)	*Hypericum gentioides*
Andropogon ternarius	*Leersia virginica*
Andropogon virginicus (cover)	*Lespedeza cuneata*
Andropogon virginicus (density)	*Lespedeza hirta*
Anthaenantia rufa	*Liatris elegans*
Aristida purpurescens	*Liatris tencifolia*
Aristida tuberculosa	*Liatrus sp.*
Arundinaria galgantium	*Liatrus squarrulosa*
Aster 1	*Onoclea sensibilis*
Aster 2	*Opuntia humifusa*
Aster 3	*Osmunda cinnomomea*
Aster 4	*Osmunda regalis*
Aster 5	*Panicum chamaelanche* (cover)
Aster 6	*Panicum chamaelanche* (density)
Aster dumosus	*Panicum clandestinum* (cover)
Aster laterifloris	*Panicum clandestinum* (density)
Aster tortifolias	*Paspalum notatum*
Brachyelytrum erectum	*Paspalum setaceum*
Bulbostylis ciliatifolia	*Pityopsis*
Cassia sp.	*Polypremum procumbens*
Cenchrus sp.	*Potentilla sp.*
Chasmanthium laxum	*Pterydium aquilinum var. pseudocaudatum*
Cinna arundinacea	Ragweed
Cnidoscolus stimulosus	*Rhynchosia minima*

Scientific Name	Scientific Name
Commelina erecta	*Rhynchospora microcephala*
Coreopsis major	*Schizacherium scoperium cover*
Coreopsis major var. stellata	*Schizacherium scoperium density*
Coriopsis sp.	*Schrankia microphylla*
Croton glandulosus	*Scleria bottom*
Desmodium paniculatum	Sedge 1
Desmodium sp.	Sedge 2
Digitaria ciliaris	Sedge 3
Diodia teres	*Segmaria pectinata*
Elephantopus carolineanus	*Solidago odora*
Elephantopus tomentopus	*Solidago sp.*
Erianthus sp.	*Sorgastrum nutans*
Erigonium sp.	Sphagnum moss
Erigrostis hirsuta	*Sporobolus junceus* cover
Eupatorium altissimum	*Sporobolus junceus* density
Eupatorium capillifolium	*Stylosanthes biflora*
Eupatorium jucundum (Ageratina jucunda)	*Tephrosia florida*
Euphorbia pubentissima	*Tephrosia virginiana*
Fern 1	*Tradescantia sp.*
Forb 1	*Tridens flavus*
Forb 10	*Triplasis americana*
Forb 2	Unknown
Forb 3	*Vernonia angustifolia*
Forb 4	*Woodsia obtusa*
Forb 5	*Woodwardia areolata*
Forb 6	*Xyrus difformis*
Forb 7	
Forb 8	
Forb 9	
Galactia volubilis	
Galium circaezans	
Gaura filiper	
Grass 1	
Grass 2	
Grass 3	
Grass 4	

A chronosequence study focusing on recovery of groundcover vegetation after clear cutting was conducted in 2001/2002. Groundcover vegetation was assessed within 2 major soil groups (loamy vs. sandy soils) and 4 time intervals after logging for a total of 32 sites. Military activity for these sites was low to moderate. Identification of pattern and rate of groundcover recovery following clear-cutting will aid in identification of sensitivity and rate of return of herbaceous species following low to moderate levels of disturbance and further separate natural variation from variation attributed to anthropogenic disturbance.

Within each soil type, 4 sites were selected from each of the following categories representing time since last clear-cut: 0-3, 8-10, 18-20, and >30 years. Potential sites were subjected to the same logging techniques, which included roller chopping and burning but no herbicides and had similar fire histories and slope (0-6%). While all sites were clear-cut, only sites > 30 yr. stands were thinned. All pine stands within the reservation that fit these criteria were compiled into a list from which study sites were randomly chosen. The 0-3 year sites were longleaf plantations, with no overstory and generally high groundcover. The 8-10 year sites were either longleaf or loblolly plantations (all plantations were loblolly before 1996) with no overstory above 10 feet. While overstory cover increased and groundcover decreased for 15-20 year sites, the highest canopy cover was found on the oldest sites (>30 years).

Five random subplots were selected at each of the 32 sampling sites. Each subplot was categorized as: skid trail/road, low disturbance, or unknown based on a visual assessment of the disturbance. Overstory canopy cover was measured with a concave spherical densiometer by averaging the readings of the four cardinal directions from the center point of the subplot. Radiating from the center point, 3-meter transects were established at 0°, 120°, and 240°. Along each transect, woody (<2m in height) cover by species was measured. Aerial herbaceous vegetation cover by species was estimated using foliar ocular observation in 1 m^2 quadrats at the center point and at the terminus of the 240° transect.

An undisturbed soil core was taken adjacent to each herbaceous quadrat for laboratory bulk density determination. Additional soil samples were collected at the terminus and centerpoint of each transect and at each center point for a total of 4 samples; 20 overall for the site. These samples were combined in a single container for each subplot. Texture, pH, organic matter, total nitrogen, and total carbon were measured for these composite samples.

CCA was used as an ordination technique to determine the relationship between species cover and measured environmental variables. Initial CCA analysis and regression found no significant relationship between pH, organic matter, total nitrogen and total carbon, and variation in vegetation. Additional CCA analysis included only environmental variables contributing to the variation in vegetation including time since clear-cut, percent clay and sand, canopy cover (DENS), and soil bulk density (BD).

Sites were originally classified as sandy or loamy based on soil maps. After textural analysis of samples collected at each site revealed disagreement with the soil map, sites were reclassified to reflect quantified textural differences.

Analysis of chronosequence data continued in FY03, resulting in a master's thesis.[3] Results are presented below in FY03 Results and Summary.

4.4.3 Watershed Hydrology

Soil-water Storage Estimation

Soil-water content and storage dynamics play a dominant role in determining hydrologic processes (e.g., infiltration and runoff) and biological processes (e.g., biogeochemical rates; plant-water stress) in watersheds. Efforts of the Purdue group under Dr. Suresh Rao were focused on long-term monitoring of water storage dynamics in the Bonham-1 watershed and linking this information to stream flow monitoring data being collected by Dr. Jennifer Jacobs (University of Florida). Spatial distribution of soil hydraulic properties is also needed as input in spatially-distributed hydrologic models for forecasting infiltration, recharge, and stream flow.

Monitoring how distributed storage changes both spatially and temporally was begun in FY01. Soil moisture was measured and logged at several distributed locations and along specific transects in the Bonham-1 subwatershed, a relatively low-impact catchment in D13 (Figure 4-6). Preliminary measurements were used to estimate the total water storage and spatial moments of water content within the catchment (Figure 4-7).

Distributed soil moisture content was sampled both in June 2001 and August 2001. Analysis shows relatively dry upland soils with increasing water content on the hill slopes. The majority of the water storage is confined to the areas immediately adjacent to the stream channel. More data is needed to observe water redistribution activity under different climate and seasonal situations as well as a more detailed characterization of moisture dynamics in riparian areas. Soil moisture measurements will also be extended to other watersheds as well as impacted areas for comparison purposes.

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[3] Archer, J. K. 2003. Understory vegetation and soil response to silvicultural activity in a southeastern mixed pine forest: A chronosequence study. M.S. Thesis. University of Florida

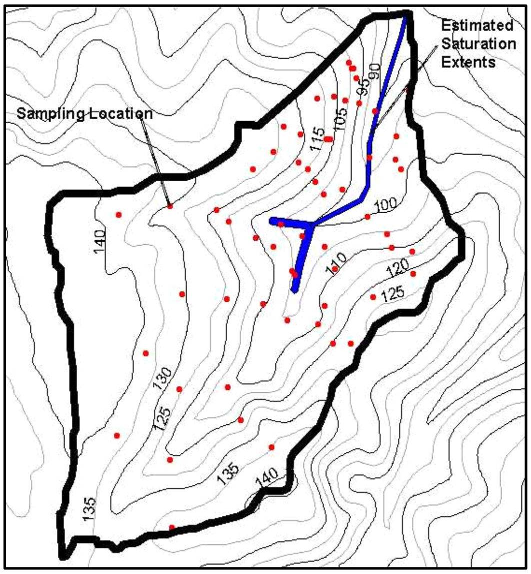
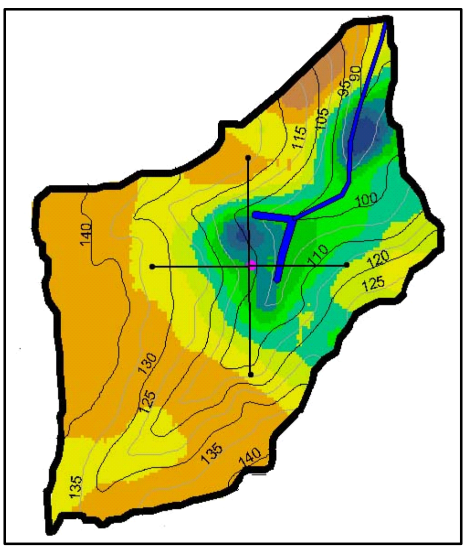


Figure 4-6. Seventy sampling locations in D13 catchment of Bonham-1 watershed – August 8, 2001.



Spatial Moment Summary

	w/o Stream Zone	w/ Stream Zone
Total Water (m3)	38,896	42,880
Centroid - x (m)	710,313	710,330
Centroid - y (m)	3,588,465	3,588,488
Centroid - z (in)	13	13
stddev - x (m)	251	247
stddev - y (m)	274	276
stddev - z (in)	9	9
Total Volume (m3)	580,710	
Average Water Content	0.067	0.074

Figure 4-7. Integrated water content in upper 30 inches, D13 Bonham-1 watershed - August 8, 2001.

Shown on the plot are also the spatial mean water content (red point) and standard deviation about the mean (black lines).

Every two months since June of 2001, point water content measurements were obtained in the Bonham-1 watershed using the Delta-T® TH2O Soil Moisture Meter. Sample locations were predetermined at relatively regular intervals over the 95.1-ha (~0.3-sq mi) watershed using 50-meter contour lines as references. Measurements were used to estimate the total water storage and spatial moments of water content within the catchment. Near-stream spatial soil saturation limits were recorded to compare previous near-stream saturation delineation. At each sample location, water content measurements were taken at the soil surface as well as depths of 15, 30, 45, 60, and 75 cm by first digging with a soil auger to the desired depth, inserting the probe into the soil, and then obtaining a water content reading. This process was repeated at all sampling locations on a given sampling campaign (about 50).

Each depth was treated as a horizontal cross-section of the watershed and was analyzed separately for estimating soil-water storage. To interpolate water content between measured points, a statistical distribution of water content was computed for each depth to eliminate potential outliers. Then variograms were computed and used to develop spatial water content models by ordinary kriging. GEO-EAS® software (EPA software) was used to calculate and assign unbiased water content values over the Bonham-1 watershed for each depth. Maps of soil-water storage distribution were generated from the GEO-EAS grid output using ARCVIEW® (Figure 4-8).

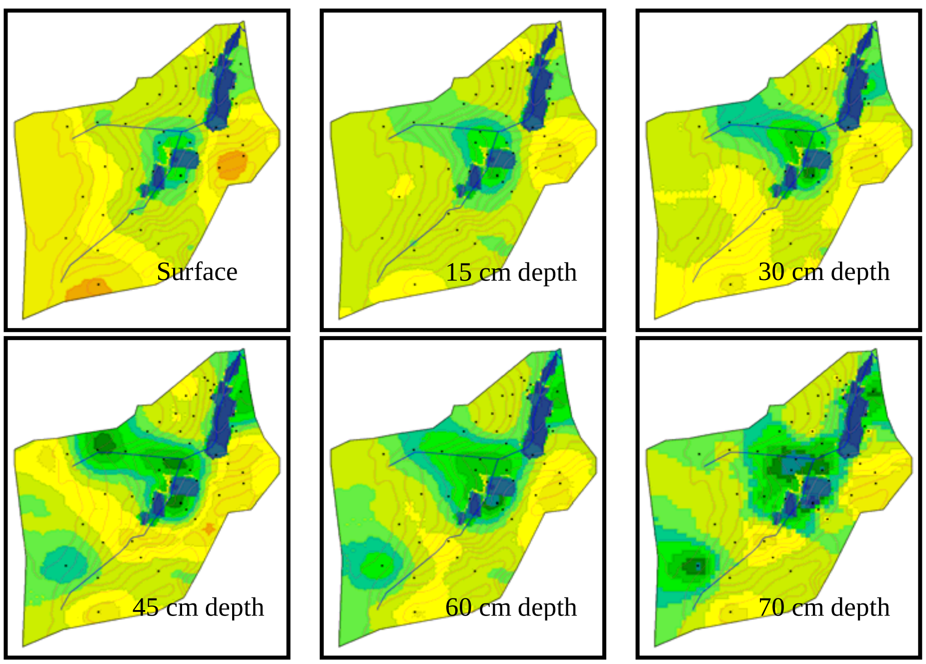


Figure 4-8. Depth-specific water content estimation maps of Bonham-1 watershed for March, 2002. Blue areas contain more water than yellow and brown areas.

Results and Discussion

Total water storage of each depth was calculated and added to soil-water storage in the riparian area to yield the total soil-water storage. Based on a preliminary analysis of a water balance, the current method of ordinary kriging of water content does not call for more spatial water content information than has been gathered to take advantage of its full potential as an unbiased estimator.

After a 1-year cycle of soil-water storage monitoring, we have observed that a temporal pattern of total soil-water storage emerges (Figure 4-9). Total volume of soil-water storage measured during drier months (June through August) was consistently lower than the higher storage that was observed during wetter months (September through May). This observation will be explored by statistical moment analysis that will define total mass of water, the centroid (center of mass of water), and standard deviation. We are investigating the temporal stability of the spatial patterns in soil-water storage as it relates to vegetation, soil type, and rainfall patterns.

When compared to volumes estimated from precipitation and hydrograph data, our estimated soil-water storage appeared to attribute an appropriate volume when compared to the expected volume of precipitation minus hydrograph volume (Table 4-11).

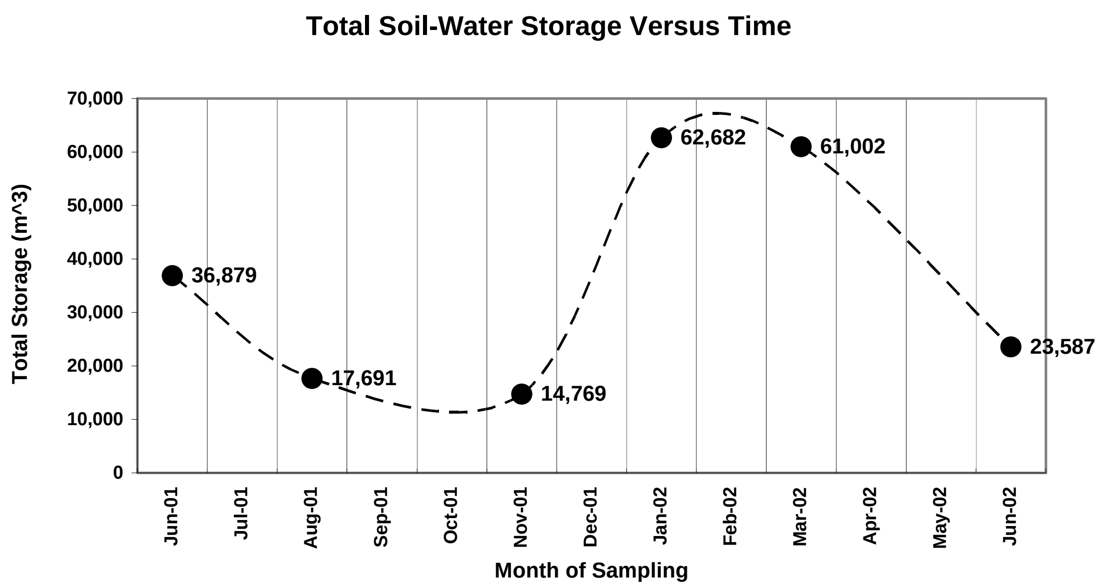


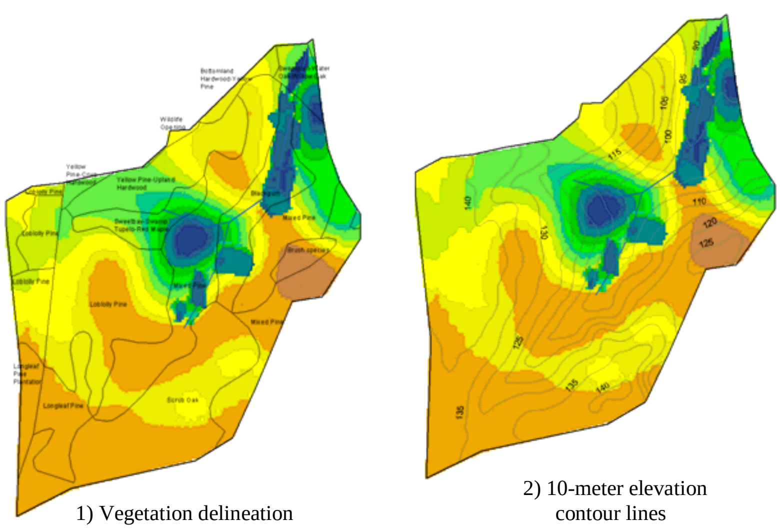
Figure 4-9. Observed temporal trend in total soil-water storage.

Table 4-11. Water balance for 18 through 22 January.

Throughfall is estimated as 95% of the precipitation. Storage is the soil-water storage estimated from point-interpolated measurements. Storage (hydrograph) is throughfall minus hydrograph volume. Precipitation and hydrograph data courtesy of Jennifer Jacobs and Shirish Bhat, University of Florida.

Source	Vol Water (m^3)
Precipitation	23,850
Throughfall	22,660
Hydrograph	431
Storage (δθ)	21,915
Storage (hydrograph)	22,229
Evapotranspiration	314

Now that spatial soil-water storage has been developed, multivariate analysis will be performed to find correlation between water content and landscape features (slope, elevation, vegetation patterns, etc.). Initially, digital delineation of vegetation and 10-meter contour lines overlaid on the soil-water storage maps to explore the idea that water content could be spatially dependent on landscape features (Figure 4-10). Then, a preliminary statistical analysis of Bonham-1 watershed using a principal component approach showed that when water content was compared to slope and elevation it could only account for 22% of the variation and was not a principal component. Although this preliminary analysis did not confirm our hypothesis that water content is spatially dependent on landscape features, different landscape features (e.g., understory vegetation; trees) need to be considered in another multivariate analysis.



1) Vegetation delineation

2) 10-meter elevation contour lines

Figure 4-10. Vegetation delineation (1) and contour lines (2) overlaid on a total soil-water storage map that was derived from the sampling campaign in January 2002.

Channel Sediment Sampling

In June of 2001, an exploratory sampling effort was made to obtain sediment samples from several channels on Rowan Hill and Cannons. These sediment channels would potentially be a source of sediment in Bonham Creek. The thought behind this effort was that a historical approach to erosion and sedimentation could be found by analyzing the sediment deposition in the channels. Sampling was done at depth and the original A-horizon (Ab horizon) was recorded. Particle size distribution was characterized in the lab, but no significant variation in sediment size distribution was found at depth or along the length of any channel. Results suggest that an ongoing monitoring of sedimentation would yield better results and would have more potential to describe historical sedimentation events.

Watershed Hydrologic Budget

Stream flow, stage, rainfall, and throughfall data collection was continued and expanded during FY01. Period 1 of 4 for the throughfall study was completed and initial results show a distinct signature among the five vegetation categories into five different groups: wetland, pine plantation, hard wood, mixed, and pine. The spatially distributed hydrological input model was developed, including a Gash throughfall model coupled to a GIS system that uses landuse coverages. Preliminary hydrologic modeling efforts in Bonham-2 were conducted using TOPMODEL. The model was run and produced reasonable results.

Activities

The project objectives are to identify physical variables associated with hydrologic processes as potential indicators. Toward that end, routine measurements of watershed scale hydrologic parameters were conducted in FY02. Specific monitoring activities during the past year include precipitation monitoring; stream flow gaging; throughfall measurements; water content sampling; and soil water, groundwater, and stream water sampling. Hydrological sampling occurred approximately twice per month during FY02.

The throughfall study initiated in FY01 was completed in June 2002. Throughfall and stemflow were measured for a 1-year period in five different land types (wetland, pine plantation, hard wood, mixed, and mature pine) using four replications (Figure 4-11). In addition, measurements were made in four additional mature pines and wetland plots to characterize the impact of canopy cover on water input. All trees in study plots were identified and characterized by species count, height, canopy radius, and diameter at breast height (DBH). Bi-weekly measurements of throughfall, stemflow, and canopy cover were made throughout the study.

Stream flow and water quality monitoring studies continued throughout FY01-02. The stream flow was continuously monitored in Bonham-1, Bonham-2, and Oscar-1. Water quality was sampled in nine stream locations (Figure 4-12). Analysis of stemflow, throughfall, and precipitation chemistry were made in significant land and forest communities. Measurement parameters include NH_4-N, TKN, TP (total phosphorus), TOC, Chloride, DOC, SRP (soluble reactive phosphorus), NO_3-N (nitrate), pH, temperature, and conductivity. A focused, single watershed experiment was established in Bonham-2 during the Summer 2002. The existing instrumentation to monitor throughfall, precipitation, and streamflow was expanded to include groundwater levels and chemistry, soil water chemistry, and surface water chemistry. Lysimeters and groundwater wells are constructed and installed. The sampling design consists of four riparian transects that are perpendicular to the stream. There are three wells in each transect located at near stream, midpoint of the riparian area, and at the toe of the upland area. Two lysimeters are collocated with each well. The lysimeters are located above and below the main rooting zone. There are a total of 24 lysimeters installed for soil water sampling. Water levels are measured continuously. Water chemistry samplings are conducted bi-weekly.

A joint effort between the University of Florida (Jacobs) and Oak Ridge National Laboratory (Garten and Ashwood) was established to generate a distributed, regional model of excess nitrogen at Fort Benning and to develop a hydrologic modeling framework that links the nitrogen model to the stream water chemistry. This effort was continued during FY03.

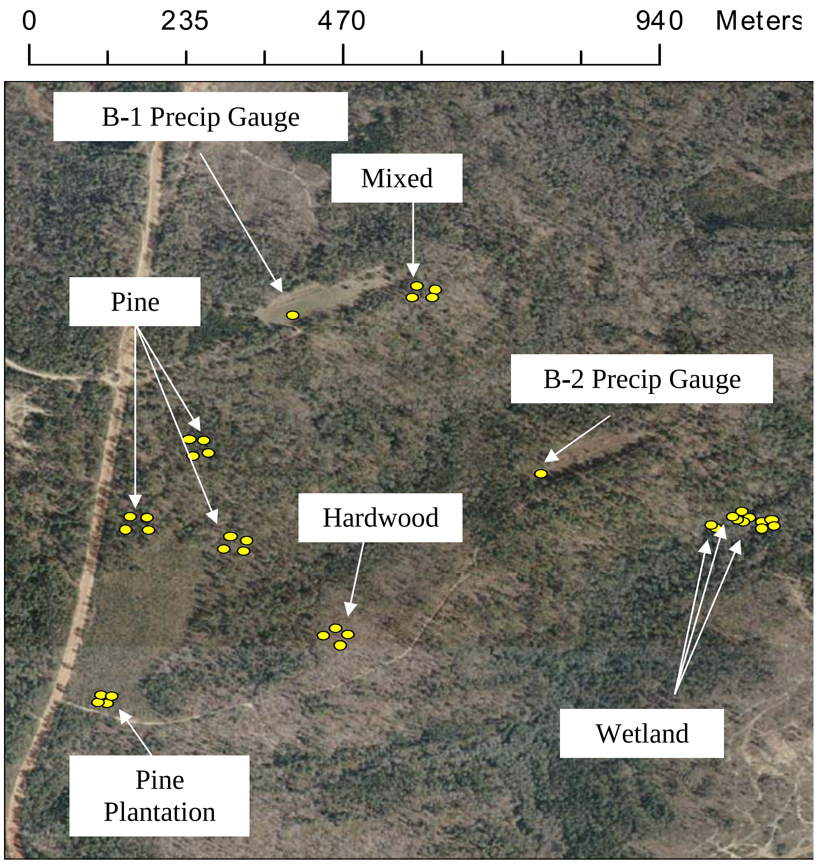


Figure 4-11. Throughfall and stemflow sampling locations in D12/D13 catchments.

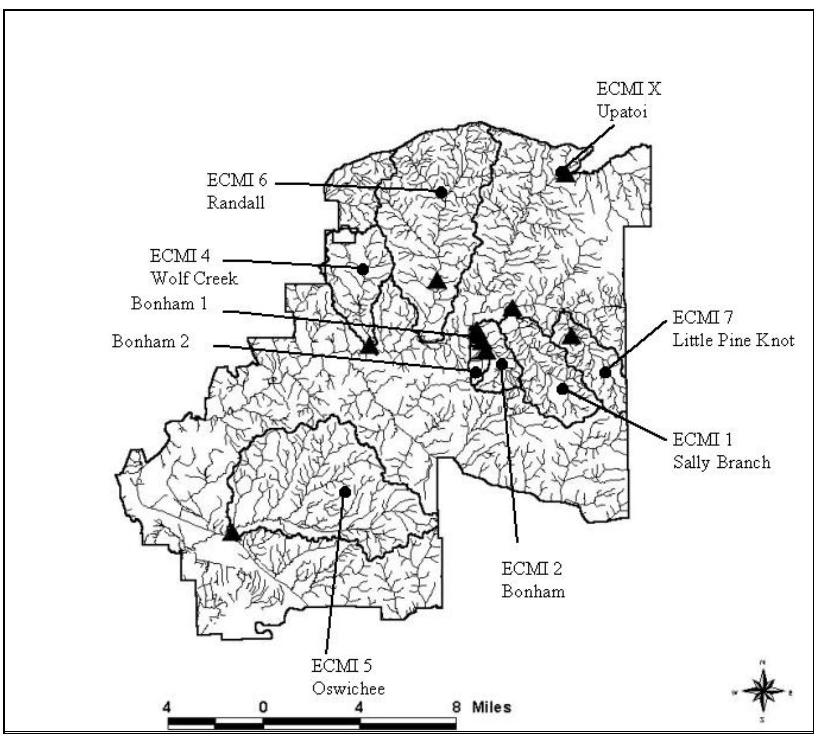


Figure 4-12. Stream water chemistry sampling locations.

Results and Discussion

The impact of vegetation community and dynamics on water input were characterized by the throughfall study. A strong seasonal variation in canopy cover was observed (Figure 4-13). This variation was determined to have a significant influence on the characterization in water input for intra-annual time-scales. The Gash model parameters by forest type were developed and the model was successfully applied to simulate interception (Figure 4-14). Inclusion of seasonal canopy dynamics improved the model results for all land uses. Variations in tree species contribution among forest types and understory contribution to canopy cover measurements were found to have a significant impact on local interception loss calculations. These results suggest that forests that are comprised of multiple species may require species-based corrections to model parameters. In addition, the relative composition of overstory and understory to interception needs to be considered prior to applying experimentally determined parameters to other sites. New methods were developed to correct canopy cover measurements and canopy storage capacity values that provide a preliminary approach to characterize canopy specific parameters on the basis of site characteristics.

Examination of the watershed on an individual forest type scale, the lumped approach to throughfall modeling, underpredicts annual throughfall for all forest types. Most significantly, it underpredicts throughfall by 27.2% for hardwood forests and 22.6% for wetland forests when an annual average canopy cover is used in the Bonham watersheds. A lumped model also underpredicts throughfall by 23.5% for hardwood forests and 23.6% for wetland forests using seasonal canopy cover. This error is of particular concern for the riparian wetland forest as the watershed storm response is most critical for areas closest to the stream in watersheds dominated by the saturation excess mechanisms of runoff generation. When shorter temporal periods are examined (seasonal instead of annual), the associated errors with the lumped approach are even more pronounced. For example, the lumped approach predicts wetland throughfall within 2.6% of the spatially distributed approach using seasonal canopy cover during the winter. However, the difference is over 25% for the remaining seasons. A large variation is also seen in the pine plantation communities where the error ranges from a 3.3% overprediction to a 33.2% underprediction in throughfall.

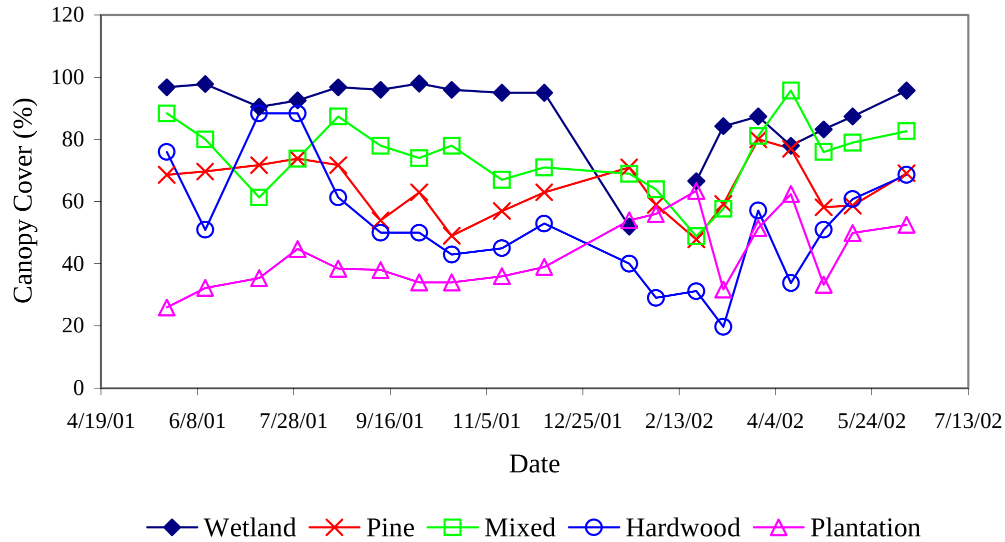


Figure 4-13. Canopy cover measurements for the five forest types.

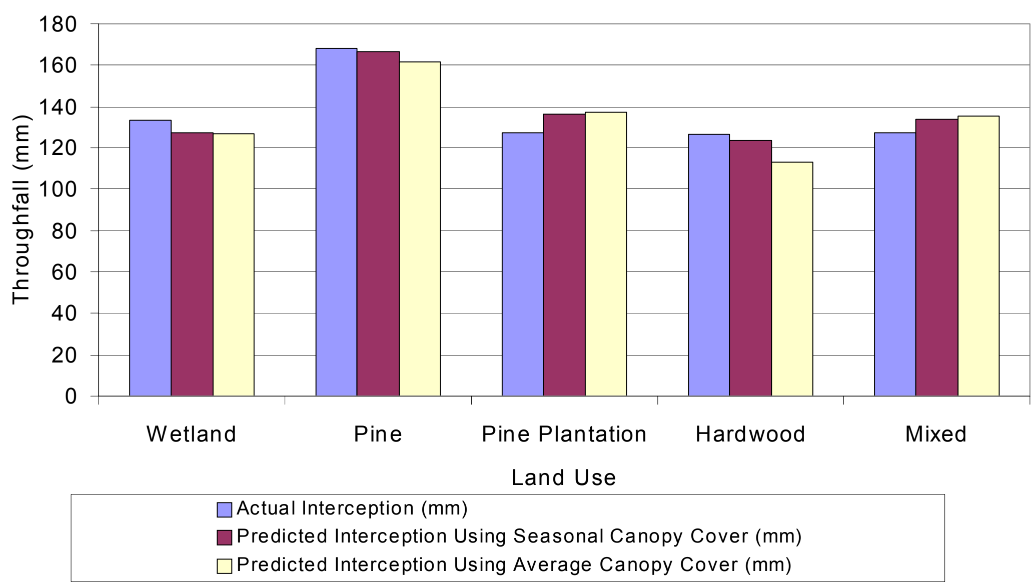


Figure 4-14. Measured and modeled interceptions results using the Gash model with and without seasonal canopy cover by forest types.

Stream Water Quality

Water quality measurements revealed low levels of most nutrients. Significantly higher levels of some nutrients (TKN, sulfate, DOC, TOC, NH3, Cl) were observed in throughfall and stemflow than in soil and stream waters. A seasonal increase in stream water nitrogen was observed during the winter months (Figure 4-15). This increase coincided with the decreased canopy cover in the wetland and hardwood communities (Figure 4-13). Preliminary modeling results suggest that an understanding of hydrologic pathways is necessary to link excess nitrogen to stream water chemistry.

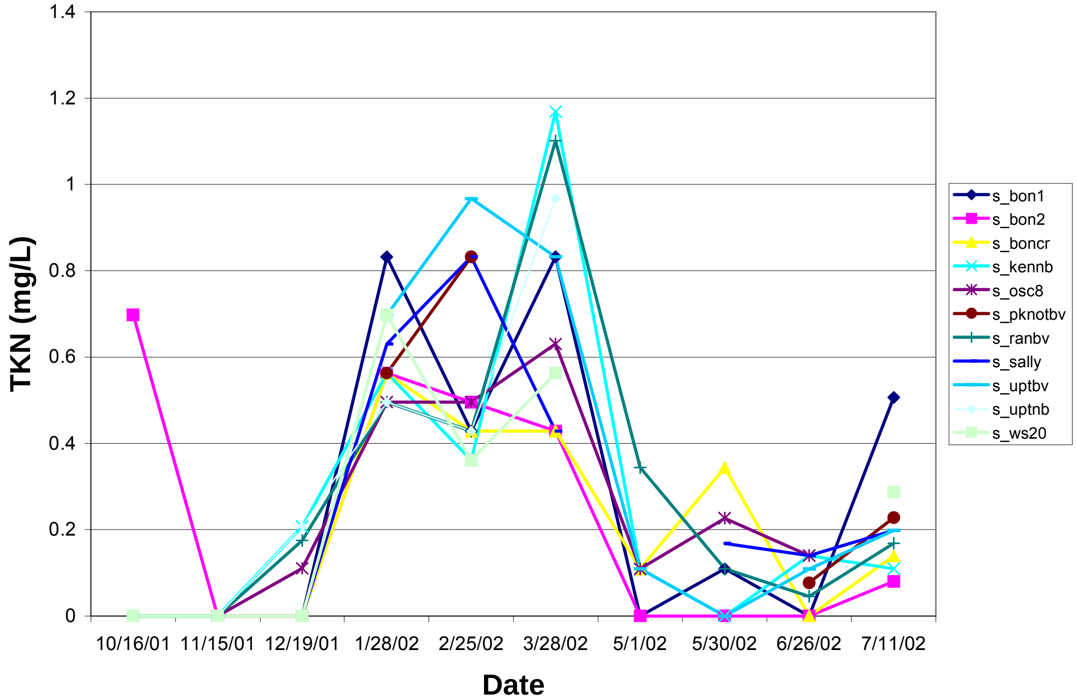


Figure 4-15. Measured water quality from October 2001 to July 2002 for the UF and ECMI watersheds.

4.5 Project Milestones (FY03)

Table 4-12 lists the milestones for FY03, as listed in the FY03 Execution Plan, for the University of Florida-Purdue University research team.

Table 4-12. FY 2003 milestones.

Task	Due Date	Status
Prepare and submit peer-reviewed manuscripts	03/2003 07/2003	Two publications submitted; six in preparation
Validation of Selected Soil Biogeochemistry Indicators through re-sampling and soil analysis of a subset of Phase I sites	06/2003	Soil sampling completed. Soil analysis complete. Data analysis on-going.
Litter Decomposition and Carbon Dynamics study	06/2004	Initial litter bags deployed. First through third (3, 6, and 9 month) litter bags and soil samples recovered.
Correlation of Soil Biogeochemistry with Watershed Hydrology Model	09/2003	Soil sampling and analysis of12/02-samples completed. Seasonal sampling (6/03) completed, soil analysis ongoing.
Refinement of Hyperspectral Analysis of Soils	06/2003	Field sampling completed. Soil analysis complete; data analysis complete. Manuscript in preparation.
Analysis of vegetation community structure and composition with respect to disturbance and soil characteristics	06/2003	Manuscript in preparation.
Further analyses of Sediment Water Storage to find seasonal or periodic variation trends	06/2003	Manuscripts in preparation.
Extension of the throughfall model to generate distributed water input data for the Watershed Hydrologic Budget	09/2003	Data collection completed. Model parameterization underway
Submit field data to repository	06/2003	Submitted 08/03

4.6 FY03 Results and Summary

A summary of accomplishments for FY03 are presented below, for soil biogeochemistry, vegetation, and hydrologic components.

4.6.1 Soil Biogeochemistry

During FY03, two studies were initiated. The first was a litter decomposition study aimed at determining temporal responses in plant litter decomposition as influenced by land use. The second was soil sampling along two subwatersheds of Bonham Creek, which was intended to provide information regarding soil nutrient storage for development of the watershed hydrologic model (see Watershed Hydrologic Budget, page 67).

Litter Decomposition

The litter decomposition study was initiated in December 2002 at upland and wetland sites corresponding to high, moderate, and low impacts (six sites total). Leaf and pine needle litter was collected from litter traps placed at a site within the Bonham watershed. Litter will be air dried, weighed, and placed in polyethylene mesh bags and placed on site in the six locations. Three bags will be retrieved every 3 months for 1 year. Soil cores will be collected at each site (0-20 cm) corresponding to each litterbag collected. Four cores will be collected and composited for a single sample corresponding to each litter bag. Litter will be collected and deployed similarly for year two, with bags and soil samples collected at 3 and 6 months.

Both litter and soil will be analyzed for the following parameters: Loss On Ignition (LOI); Moisture Content; Total Organic Carbon (TOC); Dissolved Organic Carbon (DOC); Total Kjeldhal Nitrogen (TKN); Microbial Biomass Carbon (MBC); Microbial Biomass Nitrogen (MBN); Potentially Mineralizable Nitrogen (PMN); Extracellular Enzyme Activity (phosphatase, glucosidase, peptidase, dehydrogenase); and Microbial Respiration (CO_2 production). Field measurements at each site will include in situ respiration, and soil and air temperature. Data will be analyzed for relationships between carbon quality/quantity and microbial community structure and activity. Correlations between detrital turnover and soil microbial communities will be determined. The sampling and analyses of litter and soil are ongoing.

Soil Nutrient Storages for the Watershed Hydrology Model

Soil samples were obtained from transects along two second order streams (Bonham-1 and Bonham-2) in support of the Riparian Ecosystem Management Model. Soil was sampled to a depth of 10 cm using a 6.5-cm diameter corer. Samples were obtained along transects approximately 5 m from the channel on both sides of the stream at approximately 80-m intervals. A second sampling of riparian soils was conducted in June 2003 in Bonham-2 in order to account for seasonal trends in carbon and nitrogen inputs to the watershed. Biogeochemical analyses are completed on Fall 2002 samples, and analyses of most recent samples are ongoing. Results will be used to determine values for soil nutrient compartments of the hydrologic model.

Soil Biogeochemistry Validation

Soil sampling for validation of selected biogeochemical parameters was completed for a subset of Phase I sites (Bonham watershed). Additional field measurements were made at each site including soil moisture, soil respiration, and hyperspectral reflectance measurements of surface soils. Soil chemical analyses are completed.

Hyperspectral Analysis of Soils

Hyperspectral analysis has been conducted under laboratory conditions in order to test the discriminant function model that was developed using Phase 1 reflectance measurements. Data analysis to quantify the similarity or dissimilarity between Phase1 reflectance measurements and these new soil reflectance measurements using different similarity indices has been completed and preliminary results presented below.

Preliminary Results of Hyperspectral Analyses

In-situ reflectance measurements were not used to test the Phase 1 discrimination model due to low overall reflectance resulting from soil moisture and because the variability in the reflectance values was much higher than the more stable in-lab spectral signatures. To quantify the similarity between in-situ reflectance measurements and other reflectance measurements (top 2 cm in-lab, top 20 cm in-lab, and Phase1 top 20 cm in-lab), a matching technique proposed by Drake et al.[4] was used. Data was first smoothed using the Savitzky-Golay 11 point smoothing algorithm.[5] Each soil signature was also normalized about the mean.[6]

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[4] Drake, N.A., Mackin, S., Settle, J.J. 1999. Mapping Vegetation, Soils, and Geology in Semiarid Shrublands Using Spectral Matching and Mixture Modeling of SWIR AVIRIS Imagery. Remote Sens. Environ. 68: 12-25

[5] Savitzky A and Golay M J E (1964). Smoothing and differentiation of data by simplified least squares procedure. Anal. Chem. 36, 1627-1638.

[6] Drake, N.A., Mackin, S., Settle, J.J. 1999.

$$D_i = \frac{x_i - \bar{x}}{\sum_{n=1}^{i} \left| x_i - \bar{x} \right|} \qquad \text{Equation 1}$$

D_i = the normalized value for wavelength i
X_i = reflectance value for wavelength i
$\bar{x}$ = mean value of the spectrum
n = number of wavelengths

The following distance function was used to do the matching:

$$c_i = 1 - \sum_{i=1}^{n} \left| D_{ij} - D_i \right| \qquad \text{Equation 2}$$

D_{ij} = normalized data value of wavelength i for library spectrum j
D_i = normalized data value of wavelength i for the unknown spectrum.
c_j = similarity index (varies between 1 and –1 for each of the j library spectra. Values of 1 represent a perfect fit, and values below zero are rejected, as the fit is poor)

Conclusions

1. Top 20 cm in-lab soil reflectance measurements of Phase 3 showed the same degree of separation between low, medium, and severe sites as shown by Phase1 top 20 cm soil reflectance measurements. Continuous gradation and overlap between the disturbance classes was still evident. There wasn't any improvement over the discrimination that was obtained using Phase 1 reflectance measurements. Soil reflectance measurements in general showed a sound temporal stability for use in discriminating between the disturbance classes.
2. Based on 41 sites, top 2 cm in-lab reflectance measurements showed a satisfactory discrimination between low, medium, and severe sites. It successfully discriminated a larger number of severely disturbed sites. The feasibility of using top 2 cm soil reflectance measurements with Phase1 top 20 cm reflectance based models cannot be firmly concluded at this point because of the small dataset of Phase 3.
3. Based on the raw reflectance measurements without any data preprocessing, Phase3 surface in-situ soil reflectance measurements showed the most similarity with Phase 3 top 2 cm in-lab soil reflectance measurements followed by Phase 3 top 20 cm in-lab and Phase 1 top 20 cm in-lab soil reflectance measurements.

4. With a smoothing function used and derivatives taken at a 1-nm interval, Phase 3 in-situ soil reflectance measurements showed most similarity with the Phase 3 top 2cm in-lab reflectance measurements, followed by Phase 1 top 20cm in-lab reflectance measurements and Phase 3 top 20cm in-lab reflectance measurements.
5. The relationship between the moisture content in the soil and the degree of similarity between Phase 3 in-situ soil reflectance measurements and other sets of reflectance measurements (Phase 3 top 2 cm in-lab, Phase 3 top 20 cm in-lab) showed that as the moisture in the soil increases by more than 10% the degree of similarity significantly decreases.

4.6.2 Vegetation

The chronosequence study conducted in 2000/2001 focused on recovery of ground cover vegetation after clear cut. Further analysis and completion of a master thesis from the chronosequence data was accomplished in 2003. Ground cover vegetation was accessed within 2 major soil groups (loamy vs. sandy soils) and 4 time intervals after logging for a total of 32 sites. Military activity for these sites was low to moderate. Identification of pattern and rate of ground cover recovery following clear cutting will aid in identification of sensitivity and rate of return of herbaceous species following low to moderate levels of disturbance and further separate natural variation from variation attributed to anthropogenic disturbance.

Within each soil type, 4 sites were selected from each of the following categories representing time since last clear-cut: 0-3, 8-10, 18-20, and >30 years. Potential sites had been subjected to the same logging techniques, which included roller chopping and burning but no herbicides, and had similar fire histories and slope (0-6%). While all sites were clear-cut, only of sites > 30 yr stands were thinned. All pine stands within the reservation that fit these criteria were compiled into a list from which study sites were randomly chosen. The 0- to3-yr sites were longleaf plantations, with no overstory and generally high ground cover. The 8- to 10-year sites were either longleaf or loblolly plantations (all plantations were loblolly before 1996) with no overstory above 10 feet. While overstory cover increased and ground cover decreased for 15- to 20-yr sites, the highest canopy cover was found on the oldest sites (>30 years).

Five random subplots were selected at each of the 32 sampling sites. Overstory canopy cover was measured with a concave spherical densiometer by averaging the readings of the four cardinal directions from the center point of the subplot. Radiating from the center point, 3-meter transects were established at 0°, 120°, and 240°. Along each transect, woody (<2m in height) cover by species was measured. Aerial herbaceous vegetation cover by species was estimated using foliar ocular observation in 1-m^2 quadrats at the center point and at the terminus of the 240° transect.

An undisturbed soil core was taken adjacent to each herbaceous quadrat for laboratory bulk density determination. Additional soil samples were collected at the terminus and centerpoint of each transect and at each center point for a total of 4 samples; 20 overall for the site. These samples were combined in a single container for each subplot. Texture, pH, organic matter, total nitrogen, and total carbon were measured for these composite samples.

Data Analysis

Canonical correspondence analysis (CCA) and nonmetric multidimensional scaling (NMDS) analysis identified time since clear cut as the most important factor influencing herbaceous species distribution and abundance. To describe the value of different species for indicating time since clear cut, the Dufrene and Elegendre[7] method of calculating species indicator value was used. This method produces an indicator value between zero (no indication) to 100 (perfect indication). To receive a perfect score, the presence of a species would point to one of the age classes for time since clear-cut without error (always present and exclusive to that group). A randomization test was used to test for significance of the indicator value.

Results and Discussion

A total of 47 woody species were encountered (Table 4-13). Species richness in age classes from most recently clear-cut to the oldest sites was 36, 31, 37, and 32, respectively. The most abundant and frequent species in all age classes was *Rubus* sp. Indicator analysis identified *Gaylussacia mosieri* (indicator value = 43.7; p=0.028) and *Cary* spp. (indicator value = 31.1; p = 0.072) as the only significant indicators of age class. *Gaylussacia mosieri* occurred most frequently with highest cover in the 30- to 80-year-old age class but also occurred infrequently in younger age classes. *Carya* sp. were indicators of the 15- to 18-year age class.

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[7] Dufrene, M. and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monographs 67:345-366.

Table 4-13. Mean cover (%) and frequency (%) for woody species in four age classes indicating years post clear cut.

Woody Species	0-3		8-10		15-18		30-80	
	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.
Acer rubrum	0	0	0	0	t	1	0	0
Callicarpa Americana	0.4	3	0	0	0.4	2	0	0
Campsis radicans	t	1	0	0	0	0	0	0
Carya sp.	t	1	t	1	0.5	4	0.1	1
Cornus florida	0.1	1	0	0	0.1	1	0	0
Corylus americana	0	0	0	0	0.1	1	0	0
Crataegus sp.	1.0	11	2.7	9	0.4	5	0.1	5
Diospyros virginiana	0.44	5	0.7	3	0.6	9	0.1	3
Gaylussacia mosieri	t	2	0.1	3	0.2	2	0.7	9
Gelsemium sempervirens	0.2	3	0.3	3	0.5	9	0.7	6
Hypericum gentianoides	0.3	7	0.1	3	0	0	0.2	3
Hypericum hypericoides	0	0	0.1	2	0.1	1	t	1
Ilex deciduas	0	0	0	0	0	0	0.1	1
Ilex glabra	0.2	1	0	0	1.3	5	0.3	2
Liquidambar styraciflua	1.8	11	2.0	12	9.0	17	3.0	16
Lonicera sp.	0.1	1	0	0	0	0	0	0
Myrica cerifera	0.1	1	0.8	2	1.1	6	1.6	8
Parthenocissus quinquefolia	0	0	t	1	t	1	0	0
Pinus glabra	0.1	1	0	0	0	0	0	0
Pinus palustris	1.2	7	7.0	16	0.1	1	0.1	1
Pinus taeda	0.1	1	6.2	17	0.4	5	0.1	2
Prunus caroliniana	t	1	0	0	0	0	0	0
Prunus serotina	0.1	2	0	0	0	0	0.1	1
Quercus alba	0.1	1	0.2	1	0.5	3	0	0
Quercus falcata	0.5	6	0.6	3	1.6	9	0.4	4
Quercus incana	0.6	8	1.3	5	0.1	1	0.1	1
Quercus laevis	0.1	1	1.3	5	1.3	4	0.2	1
Quercus laurifolia	0.4	7	1.0	8	0.4	6	0.6	10
Quercus marilandica	0	0	0.2	1	0.9	2	0	0
Quercus minima	0.4	2	0	0	0	0	0	0
Quercus nigra	0.2	2	0.6	6	t	1	0.1	2
Quercus sp. seedling	t	2	0	0	0	0	0	0
Quercus stellata	0.6	6	0.2	1	0.6	5	0.1	1
Rhus copallinum	2.0	21	2.4	14	4.5	28	1.7	18
Rubus sp.	8.3	34	6.7	31	10.6	36	3.7	21
Sassafras albidum	0.1	2	0	0	0.2	1	0.9	5
Smilax sp.	1.3	11	0.3	8	2.5	15	0.9	14
Toxicodendron pubescens	t	2	0.4	3	0.2	2	t	2
Toxicodendron radicans	0	0	0.1	2	0.1	3	t	1
Ulmus alata	0.3	4	0	0	0.2	2	0	0
Ulmus americana	0	0	0	0	0	0	t	1
Vaccinium arboreum	0.8	10	1.2	11	2.1	10	2.8	18

Woody Species	0-3		8-10		15-18		30-80	
	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.
Vaccinium elliotti	0.1	3	0.3	5	0.2	2	0.2	6
Vaccinium myrsinites	0	0	0.3	1	0.8	7	0.6	3
Vaccinium stamineum	0	0	T	1	0.2	2	0.5	3
Vitis Rotundifolia	0.3	3	T	2	0.7	8	t	2
Yucca sp.	0	0	0.2	1	0.3	1	0	0

One hundred and fifty-eight herbaceous ground cover species were encountered (Table 4-14). Species richness for age classes from most recently clear-cut to oldest sites was 80, 61, 79, and 71, respectively. Many species were rare with a total of 57 [approximately 36% of all herbaceous sp. occurring once in 32 sites, 22 (~ 14%) twice, and 12 (~ 8%) three times]. Cover and frequency for herbaceous species differed across age classes (Table 4-14). After removal of a single outlier (site with low sand content, 52%), indicator analysis identified several species representative of each of the four age classes. Analysis based on 31 sites with percent sand ranging from 67% to 91% identified *Cyperus croceaus* and *Bulbostylis barbata* as indicators of the 0-3 year age class (Table 4-15). *Andropogon virginicus*, *Dichanthelium* sp., *Sporobolus junceaus* and *Sphagnum* sp. were significant indicators of the 8-10 year age class. *Andropogon virginicus* occurred almost exclusively in the 8-10 year age class. *Pityopsis* species and *Tridens flavus* were indicators of 15-20 year class. *Andropogon ternarius*,, *Schizacharium scoparium*, *Desmodium* sp, *Hieracium* sp, *Rhynchosia tomentosa* (marginally significant) were indicators of 30-80 year old sites. *Schizacharium scoparium* and *Andropogon ternarius* are difficult to differentiate in field sampling when floral parts are unavailable. Therefore, values for these two species and those that could not be differentiated as either were summed. Indicator analysis found this complex to be a significant indicator for 30-80 year age class.

Table 4-14. Vegetation species observed as a function of years post clearcut.

Herbaceous Species	0-3		8-10		15-20		30-80	
	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.
Acalypha gracilens	0.5	12	1.3	26	0.4	14	1.3	23
Acanthaceae fam	0	0	0	0	0	0	t	1
Agalinis setacea	0.3	2	t*	1	0	0	0.2	2
Agrimonia microcarpa	0	0	0	0	0	0	0.2	1
Andropogon gerardii	0.1	2	t	1	t	1	0	0
Andropogon gyrans	0	0	0	0	0	0	0.2	1
Andropogon virginicus	0.2	1	7.0	27	0	0	1.0	4
Apiaceae fam	0.1	2	t	2	0.2	7	0.3	3

Herbaceous Species	0-3		8-10		15-20		30-80	
	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.
Aristida purpurascens	0.1	1	t	1	0	0	0	0
Aristida sp.	0.7	6	5.3	39	1.4	14	2.2	27
Arundinaria gigantea	0	0	0	0	0.2	2	0	0
Aster concolor	0.4	5	0.5	4	t	1	0.3	4
Aster dumosus	1.9	14	0.3	14	1.75	20	2.3	23
Aster linariifolius	0	0	0	0	0	0	0.3	2
Aster patens	0	0	0	0	0.2	3	0.1	1
Aster paternus	0	0	0.1	1	0.2	2	0	0
Aster solidagineus	0.2	3	0	0	0	0	0.1	2
Aster sp.	t	1	0.1	3	0.1	3	0.5	9
Aster tortifolius	0.4	4	0.3	7	0.2	6	0.6	10
Bulbostylis barbata	1.2	7	t	1	0	0	0	0
Centrosema virginianum	0.2	2	0	0	0.3	5	0.3	5
Cercis Canadensis	0	0	0	0	t	1	0	0
Chamaecrista fasciculata	0.6	13	0.2	6	1.2	21	1.1	17
Chasmanthium laxum var. sessiliflorum	0.6	6	0	0	0.2	2	0	0
Chrysopsis mariana	0	0	0	0	t	1	0.1	1
Cirsium sp.	0	0	0	0	0	0	0.1	1
Conyza Canadensis	1.2	21	0.9	10	0.2	3	0	0
Coreopsis sp.	1.0	23	3.5	42	2.7	35	3	30
Crotalaria rotundifolia	0	0	0.2	3	0	0	0	0
Crotonopsis linearis	0	0	t	1	0	0	0	0
Cyperus croceus	0.4	11	0	0	t	1	t	2
Dalea sp.	0	0	0	0	t	1	0	0
Desmodium rotundifolium	0	0	0	0	t	3	0.1	1
Desmodium sp.	0.4	6	0	0	0.4	4	1.2	10
Dichanthelium sp.	7.7	65	12.7	74	5.8	59	4.9	46
Digitaria cognata	0.1	2	0.1	3	t	1	0	0
Digitaria filiformis var. filiformis	1.1	4	0.5	5	0	0	0	0
Diodia teres	0.8	3	0	0	0	0	0	0
Elephantopus elatus	0.2	1	0	0	0	0	0	0
Eragrostis hirsute	0.1	3	0.6	10	0.9	6	0.1	2
Eupatorium aromaticum	0.1	2	0	0	0.3	3	0.2	4
Eupatorium capillifolium	3.7	24	3.9	28	2.2	17	0.7	7
Eupatorium mohrii	0.3	1	0	0	0	0	0	0
Eupatorium rotundifolium	t	1	0	0	0	0	t	1
Euthamia caroliniana	0	0	0	0	t	1	0.9	4
Fabaceae fam	0.5	4	0	0	0.8	16	0.5	5
Florichia floridana	0.1	1	0	0	0	0	0	0
Galactia microphylla	0.1	2	0	0	0	0	0	0
Galactia sp.	0.2	5	0	0	t	2	t	1
Galium pilosum	1.1	6	0.2	5	0.2	6	0.1	3

Herbaceous Species	0-3		8-10		15-20		30-80	
	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.
Gnaphalium obtusifolium	t	1	0	0	0	0	0	0
Gnaphalium sp.	0.2	7	0.2	9	0.1	5	0.2	5
Gymnopogon ambiguus	0.5	8	0.2	6	0.5	7	0.9	7
Haplopappus divaricatus	0	0	0	0	0.1	3	0.1	1
Hedyotis procumbens	0	0	0	0	t	1	t	1
Helianthemum corymbosum	t	1	0	0	0	0	t	1
Helianthus floridanus	0	0	0.1	1	0	0	0	0
Heterotheca subaxillaris	t	1	0	0	0	0	0	0
Hieracium sp.	0.1	2	0	0	0	0	0.1	5
Hypericum gentianoides	0	0	t	1	0	0	0	0
Ipomoea sp.	t	1	0	0	0	0	0	0
Juncus dichotomus	0	0	0	0	t	1	0	0
Kummerowia striata	0	0	t	2	T	1	0.1	1
Lechea minor	0.1	3	0.2	3	0	0	0.3	4
Lechea mucronata	0	0	0.1	2	0	0	0	0
Lechea sp.	0.4	7	0.3	8	T	1	0.1	3
Lespedeza hirta	0.1	1	t	2	0.1	1	0	0
Lespedeza stuevei	2.3	22	1.0	9	0.7	7	1.8	23
Liatris elegans	0.2	5	0.1	2	0.1	1	t	1
Liatris tenuifolia	0.4	4	0	0	0	0	0.1	2
Liatrus sp.	t	1	0	0	0	0	0	0
Lobelia puberula	0	0	0	0	t	2	0	0
Ludwigia sp.	0	0	0	0	t	1	0	0
Mollugo verticillata	0.1	2	0	0	0	0	0	0
Opuntia humifusa	0	0	0.1	2	0.3	6	0	0
Oxalis corniculata	0.1	3	0.1	4	0	0	0	0
Panicum anceps	0	0	0	0	t	1	0	0
Panicum rigidulum	0	0	0	0	0.2	3	0	0
Panicum verrucosum	0	0	0	0	0.2	3	0	0
Panicum virgatum	0	0	t	1	0.1	1	0.1	2
Paspalum notatum	1.1	8	0.4	8	0	0	0.1	2
Paspalum setaceum	0	0	t	1	0	0	0	0
Phlox nivalis	0.3	1	0	0	0.2	1	0	0
Piriqueta caroliniana	0	0	0.1	2	0	0	t	1
Pityopsis sp.	4.4	29	4.6	39	13.2	52	7.5	44
Poaceae fam	0	0	t	1	0	0	2.0	16
Polygala grandiflora	t	1	0	0	0	0	0	0
Polypremum procumbens	0.8	10	0.4	5	0.1	1	0.1	2
Pteridium aquilinum	1.1	8	0	0	0.5	4	0.4	3
Rhexia mariana	0	0	0	0	0.1	3	0	0
Rhus copallinum	0	0	t	1	0	0	0	0
Rhynchosia reniformis	0.4	4	t	1	0.1	2	t	1
Rhynchosia tomentosa	0.3	4	0	0	0.2	4	0.5	13

Herbaceous Species	0-3		8-10		15-20		30-80	
	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.
Rudbeckia fulgida	0	0	0	0	0.1	2	0	0
Ruellia caroliniensis	0	0	0	0	0	0	t	1
Saccharum alopecuroides	0	0	0	0	0	0	0.3	2
Andropogon ternariues/ Schizacharium scopairium	0.5	7	0.7	10	0.6	5	3.8	29
Schizacharium scoparium	4.0	24	3.0	27	7.5	36	14.0	57
Andropogon ternarius	1.0	5	0.7	5	0.8	7	2.7	30
Scleria sp.	1.0	12	0.1	5	0.2	4	1.3	10
Seymeria pectinata	0	0	0	0	0.1	1	0	0
Silphium compositum	0	0	0	0	0.3	2	0.1	1
Solidago fistulosa	0	0	0	0	0.1	2	0.4	1
Solidago latissimifolia	0	0	0	0	0	0	0.3	2
Solidago nemoralis	2.9	24	0.4	12	1.9	22	3.0	30
Solidago odora	0	0	0	0	0.6	4	0	0
Solidago sp.	0	0	0	0	0.1	2	0	0
Sorghastrum secundum	0	0	0.5	6	0.3	2	0	0
Sphagnum sp.	0	0	1.6	24	0.1	5	0.1	2
Sporobolus junceus	0	0	1.5	9	0	0	0	0
Stylisma patens	t	1	0.1	2	0	0	0	0
Stylodon carneum	0	0	0	0	0.2	1	0.1	1
Tephrosia florida	0.2	2	0	0	0	0	0	0
Tephrosia sp.	0	0	0	0	t	1	0	0
Tephrosia virginiana	t	1	0	0	0	0	0	0
Tragia urens	t	1	t	1	0	0	t	1
Trichostema dichotomum	0	0	0.5	3	0	0	0	0
Trichostema setaceum	0.3	1	0.3	4	0.1	5	0	0
Tridens carolinianus	0	0	t	1	0	0	0	0
Tridens flavus	0.2	6	0	0	1.0	11	0	0
16 Unkown herbaceous	t-1.0	t-2	t	0	t	t-1	t	t
Urtica sp.	0.1	3	0	0	T	1	0	0
Vicia sp.	t	1	0	0	0	0	0	0
Viola palmate var. triloba	t	1	0	0	0	0	0	0
Viola primulifolia	0	0	t	1	T	1	0	0
Wahlenbergia marginata	0	0	0.3	1	0	0	t	1
* =trace = < 0.1								

Table 4-15. Post clear cut age class, indicator value and significance for species identified as indicators.

Species	Post Clear Cut Age Class (years)	Indicator Value	p-value
Bulbostylus barbata	0-3	36.2	0.063
Cyperus croceus	0-3	43.7	0.034
Andropogon virginicus	8-10	62.1	0.002
Dichanthelium species	8-10	41.1	0.012
Sphagnum species	8-10	50.3	0.008
Sporobolus junceus	8-10	28.6	0.044
Pityopsis species	15-20	44.5	0.020
Tridens flavus	15-20	40.2	0.048
Desmodium species	15-20	39.8	0.034
Andropogon ternarius	30-80	36.3	0.028
Schizacharium scoparium	30-80	49.0	0.011
Schizacharium/Andropogon ternarius Complex	30-80	47.1	0.019
Hieracium species	30-80	36.7	0.024
Rhynchosia tomentosa	30-80	32.9	0.088

Most studies of vegetation recovery after a disturbance do not look at individual species responses but rather use diversity or overall cover and abundance as a measure of the understory species. A study using similar disturbances as this one found that clear-cutting and planting slash pine resulted in a decrease of woody species and an increase of herbaceous species, while overall species richness did not change with treatment.[8] More specifically, of the woody species only *Rubus* sp and *Hypericum* increased in abundance. These findings are similar to those in this study, although recovery was followed for only 2 years.

Our results suggest herbaceous species' composition and cover is more indicative of recovery time than woody species. Herbaceous species may be more sensitive than trees and shrubs to local edaphic variation,[9] and thus possibly to disturbances that alter soil characteristics. Generally, compared to herbaceous species, woody species are more broadly distributed, animal dispersed, and have underground root systems that facilitate rapid aboveground regrowth and vege-

[8] Conde, L.F., B.F. Swindel, and J.E. Smith. 1983. Plant species cover, frequency, and biomass: early responses to clearcutting, burning, windrowning, discing, and bedding in Pinus elliottii flatwoods. Forest Ecology and Management 6: 319-331.

[9] Drewa, P.B., W.J. Platt, and E.B. Moser. 2002. Community structure along elevation gradients in headwater regions of longleaf pine savannas. Plant Ecology 160: 61-78.

tative spread. This allows greater adaptation to disturbance and thus less responsiveness to change.[10] The important environmental gradients shaping herbaceous species composition were age class (8-10 yr and 0-3 yr) and bulk density, although species-environment correlation (less than 40%) was lower.

Andropogon sp, *Dichanthelium* sp, and *Aristida* sp have all been found to be more abundant soon after a disturbance (fire), followed by a slow decrease in frequency and abundance over time.[11] Increases in perennial grasses such as *Andropogon* sp and *Dichanthelium* sp following disturbance may be partially attributable to resprouting.[12] *Schizacharium scoparium* and *Andropogon ternarius* were associated with 30-80 year sites. While these species occurred in all age classes, they increased with recovery time and had higher frequency and cover values on the oldest sites. In a similar chronosequence study, Provencher et al.[13] found these grasses as potentially successful indicators of varying levels of recovery after disturbance. They grouped *Aristida* sp, *Andropogon* sp, and 11 species of *Dichanthelium* together as concomitant with soil disturbance and decreasing over recovery time. *Schizacharium scoparium* and *Andropogon ternarius* were associated with mid- to late-successional stages, and increased with recovery time.

Bulbostylis barbata and *Pityopsis* were identified as indicators of younger sites. Several herbaceous species including *Bulbostylis*, *Pityopsis* and *Eupatorium* genera have been found to be absent from mature forests older than 55 years.[14]

To a great extent herbaceous species composition was similar in the two oldest age classes. In fact, some studies found herbaceous species composition under-

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[10] Olson, M.S. and W.J. Platt. 1995. Effects of growing season fires on resprouting of shrubs in longleaf pine savannas. Vegetatio 119: 101-118.; Gile, L.H., R.P. Gibbens, and J.M. Lenz. 1997. The near-ubiquitous pedogenic world of mesquite roots in an arid basin floor. Journal of Arid Environments 35: 39-58.

[11] Lemon, P.C. 1949. Successional responses of herbs in the longleaf-slash pine forest after fire. Ecology 30: 135-145; Greenberg, C.H., D.G. Neary, L.D. Harris, and S.P. Linda. 1995. Vegetation recovery following high-intensity wildfire and silvicultural treatments in sand pine scrub. American Midland Naturalist 133: 149-163.

[12] Schmalzer, P.A. and C.R. Hinkle. 1992. Recovery of oak-saw palmetto scrub after fire. Castanea 57: 158-173.

[13] Provencher, L., H.L. Rodgers, K.E.M. Galley, J.L. Hardesty, G.W. Tanner, D.R. Gordon, J.P. McAdoo, J. Sheehan, and L.A. Brennan. 1997. Initial post-treatment analysis of restoration effects on plants, invertebrates, and birds in sandhill systems at Eglin Air Force Base, Florida. Annual Report to Natural Resources Division, Eglin Air Force Base, Niceville, Florida. Public Lands Program, The Nature Conservancy, Gainesville, Florida.

[14] Greenberg, C.H., D.G. Neary, L.D. Harris, and S.P. Linda. 1995.

goes very little change after 20 years of recovery from disturbance.[15] This has been attributed to the quick response of groundcover species to recolonization. However, highly sensitive species may take longer to reestablish after disturbance. For example, wiregrass, an important indicator species in more southern longleaf pine forests, did not recover on clear-cut sites for 90 years.[16]

Generally, only a few species stand out as possible indicators of recovery after silvicultural disturbance. Several studies have found successful herbaceous understory indicators of pine tree establishment and growth,[17] although there is the question of whether successful pine growth can be a proxy for overall landscape health. One of the criteria for a successful indicator is for the species to have low variability in response to change in environmental conditions.[18] Further studies incorporating more sites would help to clarify the validity of these species as indicators.

4.6.3 Watershed Hydrology

Watershed Hydrologic Model

Watershed hydrologic monitoring activities continued, including precipitation monitoring; stream flow gauging; throughfall measurements; water content sampling; and soil water, groundwater, and stream water sampling. Hydrological sampling was performed approximately once per month in FY03. Runoff sampling continued on an event basis using an ISCO sampler. Hydrologic and water quality data will be used to parameterize the Riparian Ecosystem Management Model which was developed by the U.S. Department of Agriculture as a

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[15] Kochenderfer, J.N. and G.W. Wendel. 1983. Plant succession and hydrologic recovery on a deforested and herbicided watershed. Forest Sci. 29: 545–558; Gilliam, F.S., and Turrill. 1993. Herbaceous layer cover and biomass in a young versus a mature stand of a central Appalachian hardwood forest. Bulletin of the Torrey Botanical Club 120: 445–450.

[16] Provencher, L., H.L. Rodgers, K.E.M. Galley, J.L. Hardesty, G.W. Tanner, D.R. Gordon, J.P. McAdoo, J. Sheehan, and L.A. Brennan. 1997. Initial post-treatment analysis of restoration effects on plants, invertebrates, and birds in sandhill systems at Eglin Air Force Base, Florida. Annual Report to Natural Resources Division, Eglin Air Force Base, Niceville, Florida. Public Lands Program, The Nature Conservancy, Gainesville, Florida.

[17] Strong, W.L., D.J. Bluth, G.H. LaRoi, and I.G.W. Corns. 1991. Forest understory plants as predictors of lodgepole pine and white spruce site quality in west-central Alberta. Canadian Journal of Forest Research 21: 1675–1683; Dibble, A.C., J.C. Brissette, and M.L. Hunter Jr. 1999. Putting community data to work: some under-story plants indicate red spruce regeneration habitat. Forest Ecology and Management 114: 275–291.

[18] Dale, V.H. and S.C. Beyeler. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1: 3-10.

tool to aid natural resource agencies and others in making decisions regarding water quality management. The model simulates movement of water and sediment, dynamics of C, N, and P, and vegetation growth within the watershed. The riparian system is characterized in the model as three zones parallel to the stream, representing increasing levels of management in the direction of the uplands. A seasonal increase in stream water nitrogen was observed during the winter months (Figure 4-16). This increase coincided with the decreased canopy cover in the wetland and hardwood communities (Figure 4-17). These results will be correlated to soil biogeochemical parameters from transects paralleling two second order streams in the Bonham watershed sampled in December 2002 and one in June 2003. This research is part of dissertation research to be completed in 2004. One publication has been submitted from this work and one is in preparation.

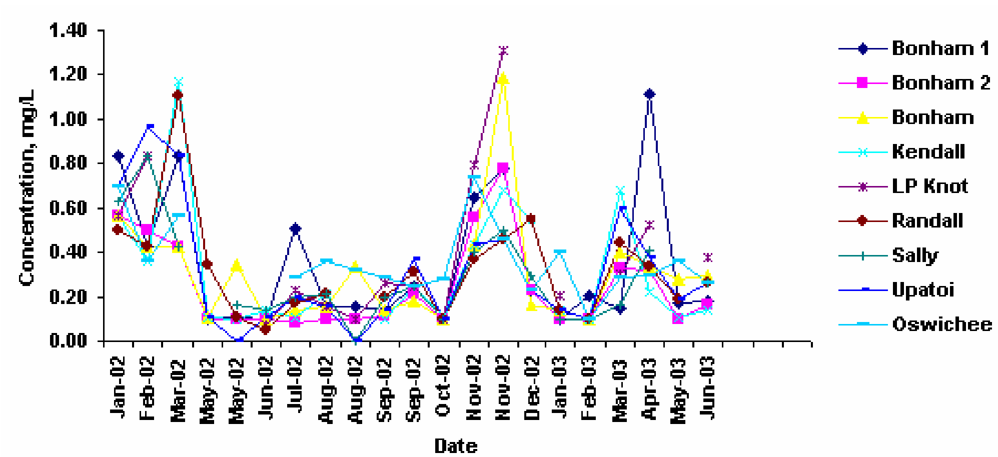

Figure 4-16. Measured water quality from October 2001 to July 2003 for the UF and ECMI watersheds.

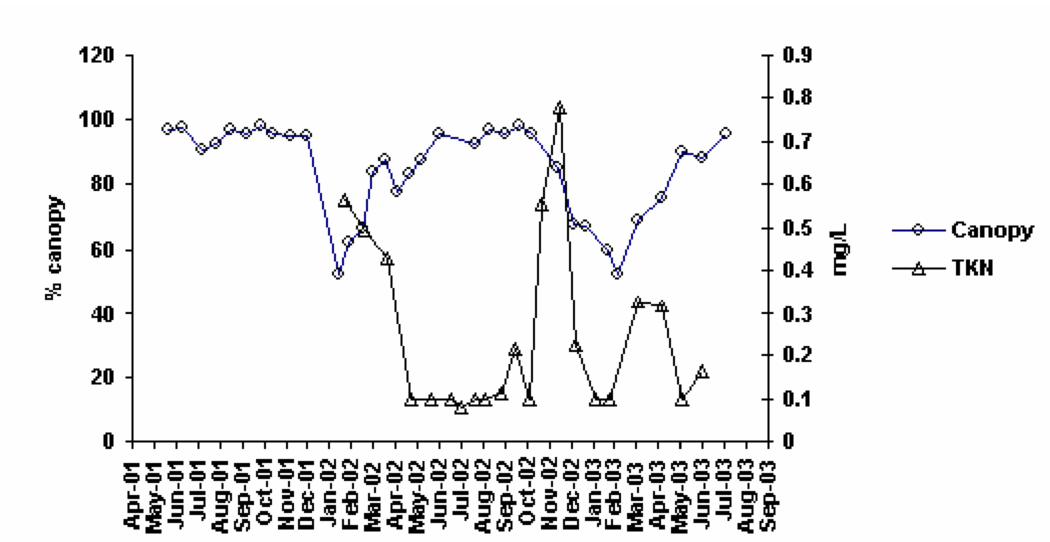

Figure 4-17. Stream TKN levels from February 2002 to June 2003 and riparian canopy cover from May 2001 to July 2003 for the Bonham-2 watershed.

Soil-water Storage Estimation

This summary of the soil water storage study is compiled from abstracts of two manuscripts being prepared for publication. The study sought to establish relationships between soil hydraulic parameters of upland forested soils and land disturbance on the ridge-tops. Similar-media scaling approaches were implemented as a compact way to assess the differences between the hydraulic properties of soil cores taken at training and nontraining sites and from off-base locations in three south-eastern states but within the same soil series. While the scaling factors themselves weakly correlated with landscape features such as slope or elevation, the scaling factors reveal a greater variance (more dispersed distribution) for the soil cores taken at the training versus nontraining sites. Geostatistical analyses also show that scaling factors for training sites have less spatial correlation than those of the nontraining sites. Additional distinctions found for the cores taken at the training sites included larger bulk densities from soil compaction, and lower soil organic carbon content (from loss of surface soil and vegetative cover) as indicated by spectral response. Localized training events denude hilltops and mix soil surface and subsurface horizons, leaving a highly variable and fragmented pattern in soil hydrologic properties, which, in turn, contributes to increased erosion potential. Because soil erosion impacts are event driven (i.e., occur at a specific point in time), an impending disturbance level at the training location cannot be easily appraised with the indicator concept. However, ecological indicators may be a viable approach for monitoring the spread of ridge-top disturbance to lower physiographic positions in the watersheds, such as the impacts of sediment deposition in the riparian wetlands and in-stream processes.

Saturated hydraulic conductivity (K_{sat}) values were measured at multiple locations in several forested watersheds at the Fort Benning, GA, military reservation. Mechanized (tank) training on ridge tops, ordnance testing, and geographic positioning of dirt roads have created highly erodible soil conditions because of denuded ridge tops and severe soil disturbance. K_{sat} measurements in the training and nontraining areas were made along transects in five subwatersheds using three field methods: (1) constant positive head infiltration, (2) constant-flux infiltration, and (3) constant negative head infiltration. Differences in K_{sat} values measured using these three methods were explained on the basis of sampling support (wetted volume) and variations with depth. In wetland/riparian areas, measured K_{sat} values were <5 cm/hr, while in training areas the K_{sat} values ranged from 3 to 36 cm/hr. The range of K_{sat} measured in disturbed areas was lower than that measured in undisturbed areas (6 to 54 cm/hr), but not as low as had been expected since field observations suggest significant soil loss from runoff and erosion events while the undisturbed areas show no evidence of erosion processes. Observed soil losses in the training areas are therefore attributed to a loss of protective vegetative cover (pine/oak forest; under-story vegetation; litter layer) and decrease in soil organic matter that otherwise protect against sediment detachment and transport. Thus, during high-intensity rainfall events with wet antecedent soil-water conditions, surface runoff and erosion occur only on the disturbed ridge tops and along roads. Storm hydrograph analyses support this observation.

4.7 Planned and Ongoing Activities FY04

4.7.1 Soil Biogeochemistry

Doctoral research investigating aggregation and soil structure as potential indicators of compaction and erosion is ongoing. Analyses of data collected in FY00-FY03 are ongoing and several manuscripts from soil biogeochemical analyses are being prepared for submission.

Litter Decomposition and Carbon Dynamics

Because of the importance of carbon dynamics in ecosystem function, and its emerging role as an indicator of disturbance, a study examining carbon storage and turnover is ongoing. Leaf bags will be used to investigate temporal responses in plant litter decomposition as influenced by land use. This study will focus on: litter turnover rates; microbial communities; nutrient availability; low, moderate, high impact areas; and bottomland vs. upland communities. A study of litter leaching has been included to examine litter degradation in more detail.

Correlation of Soil Biogeochemistry with Watershed Hydrology Model

The objective of this study is to determine soil chemical and biogeochemical parameters that affect stream and ground water chemistry. Samples have been obtained from transects paralleling Bonham 1 and 2 streams. Samples have been analyzed for: TOC, DOC, NO3, NH4, TKN, TP, SRP, Cl-, and SO4. Results from this study will be used to parameterize soil nutrient storages in the Riparian Ecosystem Management Model. Data analysis and publication preparation will be completed.

Statistical Analyses and Hyperspectral Analysis of Soils

During 2002-2003 field experiments were conducted to determine whether quantification of soil nutrient content and disturbance using spectral analyses can be done in situ, i.e. without bringing soil samples back to the lab. The spectral library of 397 Phase1 reflectance observations and the biogeochemical variables measured on them will be used develop a library matching technique to predict the biogeochemical makeup of new reflectance measurements based on library matching indices. This technique will then be compared to the predictions based on partial least squares. The accuracy of these techniques will be compared. Spectral analysis of all samples will be completed and biogeochemical analysis on 10% will be done to check model stability.

The in situ study indicated that soil moisture in the field significantly confounds interpretation of the spectra. A study to determine whether moisture content can be accounted for in predictive models will be undertaken. If successful, the procedure will be used to map soil nutrient content and disturbance for a representative watershed (Bonham) using the field spectrometer. The soil nutrient content maps will be provided to the hydrology group for comparison with stream chemistry. Statistical and data analyses and publication preparation will be completed.

4.7.2 Vegetation

Analysis of vegetation community structure and composition with respect to disturbance and soil characteristics will be completed. Similarities between silvicultural and military impacts will be investigated. An attempt will be made to sort Phase I data by time since clear cut, depending on availability of data. CCA and indicator analysis of Phase I data will be repeated after realignment by silvicultural treatment. Publications will be prepared and submitted.

4.7.3 Hydrology

Sediment Water Storage

Analysis of sediment water storage data will be completed and prepared for publication.

Watershed Hydrologic Budget

The throughfall model will be extended to generate distributed water input data for the entire Fort Benning region. A GIS framework will be used to characterize the water input. Throughfall data will be submitted to the ECMI database.

Routine stream, precipitation, and water chemistry monitoring was completed during FY03. The Riparian Ecosystem Management Model will be developed and tested. Other analyses to determine hydrological indicators of environmental change will include relationships between hydrological indicators, watershed physical characteristics, solute concentrations, vegetation classes, and land use in the University of Florida and ECMI watersheds. Analyses will be completed and prepared for publication.

4.8 Presentations

2000

Prenger, J.P., B.L. Skulnick, and W.F. DeBusk. 2000. Enzyme activity assays as indicators of environmental impact. Annual Meeting of Soil Science Society of America, Minneapolis, MN, November 5-9, 2000.

2001

Bhat, S., J.M. Jacobs, W. Graham, P.S. Rao, N. Haws, W.F. DeBusk, J.W. Jawitz. 2001. Identification of Eco-Hydrologic Indicators of Ecological Impact: Phase I Results from Fort Benning, Georgia Watersheds, Eos Trans. AGU, 82 (20), Spring Meet. Suppl., Abstract H42C-02, 2001.

Dabral, S., W. D. Graham, J. Prenger, and W. F. DeBusk. 2001. Determination of Soil, Hydrologic, and Vegetation Indicators for Military Land Management Ft. Benning Georgia. Graduate Research Forum, University of Florida, 2001.

DeBusk, W. F., and J. P. Prenger. 2001. Wetland soil biogeochemical indicators of ecological condition for military land management. Poster presented at Annual Meeting of Society of Wetland Scientists, May 28 – June 1, 2001, Chicago, IL

Jacobs, J. J., S. Bhat, W. D. Graham, P. S. C. Rao, N. Haws, W. F. DeBusk, and J. W. Jawitz. 2001. Identification of eco-hydrologic indicators of ecological impact: Phase I results from Fort Benning, Georgia watersheds. Poster presented at Spring 2001 Meeting of the American Geophysical Union, May 29 – June 1, 2001, Boston, MA.

2002

Archer, Jessica K. and D. Miller. 2002. Vegetation and soil response to timber thinning operations: a chronosequence study. Abst. Annual Meeting Society of Ecological Society of America, Tuscon AZ. August 2-9, 2002.

Chen, Weiwei, W. DeBusk, and A. Ogram. 2002. Evaluation of T-RFLP and characterization of Type II methanotroph assemblage composition in degraded and undegraded forest soils. Abstracts of the Annual Meeting of the American Society for Microbiology, Salt Lake City, UT.

DeBusk, W. F., and J. P. Prenger. 2002. Soil Biogeochemical Indicators for Wetland and Watershed Assessment. Oral presentation at Annual Meeting of Society of Wetland Scientists, June 2-7, 2002, Lake Placid, NY.

DeBusk, W. F. 2002. Determination of indicators of ecological change. Presented at the TAC meeting during April 15-17, 2002, Arlington, VA.

Prenger, J.P., B.L. Skulnick, and W.F. DeBusk. 2002. Organic C Storage and Cycling As Indicators of Ecological Condition For Military Land Management. Poster to be presented at Annual Meeting of Soil Science Society of America, November 11-14, 2002, Indianapolis, IN.

Reddy, K. R. 2002. Determination of indicators of ecological change. Presented at the TAC meeting during Oct. 28-29, 2002, Columbus, GA.

Tkaczyk, M, J.W. Jawitz, J.M. Jacobs, S. Bhat, P.S. Rao, N. Haws. 2002. Rainfall/Runoff Analysis to Investigate the Effects of Soil Heterogeneity on Watershed Response Utilizing Topmodel, Eos Trans. AGU, 83 (19), Spring Meet. Suppl., Abstract H42C-02, 2002.

Tkaczyk, M, J.W. Jawitz, J.M. Jacobs, S. Bhat, P.S. Rao, N. Haws, Rainfall/Runoff Analysis to Investigate the Effects of Soil Heterogeneity on Watershed Response Utilizing Topmodel, Eos Trans. AGU, 83 (19), Spring Meet. Suppl., Abstract H42C-02, 2002.

2003

Bhat, S., S.R. Satti, J.M. Jacobs, K. Hatfield, Ecological Indicators in Diversified Forested Watersheds: Relationships between Watershed Characteristics and Stream Water Quality in Fort Benning, GA, Eos Trans. AGU, 84 (20), Fall Meet. Suppl., 2003.

Prenger, J.P., and W.F. DeBusk. 2003. Changes In Soil Microbial Activity Related To Military Training And Forestry Activities. Poster presented at Annual Meeting Society of Ecological Society of America, Savannah GA. August 3-8, 2003.

Prenger, J.P., and W.F. DeBusk. 2003. Changes In Soil Microbial Activity In Riparian Wetlands Related To Military Training And Forestry Activities. Poster presented at Annual Meeting of Society of Wetland Scientists, June 8-13, 2003, New Orleans, LA.

Prenger, J.P., K. R. Reddy, S. Bhat, and J. Jacobs. 2003. Microbial nutrient cycling in the riparian zone of a coastal plain stream. Poster presented at the 8th International Symposium on Biogeochemistry of Wetlands, Sept. 14-17, 2003. Gent, Belgium.

5 Development of Ecological Indicator Guilds for Land Management – 1114B

Annual Report FY2003

1 October 2002 — 30 September 2003

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5.1 Project Rationale and Objective

Military land-use must be efficiently and cost-effectively monitored to assess conditions and trends in natural resources relevant to training/testing sustainability, ecosystem maintenance, and the timing and success of restoration efforts. Ecological indicators represent important land management tools for tracking ecological changes and providing early-warning detection of threshold impacts to prevent irreversible environmental damage. The objective of this research is to develop Ecological Indicators based on ecosystem-relevant criteria, multi-scale performance, and stress-response criteria, for the purpose of monitoring ecological changes directly relevant to biological viability, long-term productivity, and ecological sustainability of military training and testing lands.

5.2 Phase I: Technical Approach and Development of Ecological Indicator Guilds

Figure 5-1 illustrates our technical approach in this project to extract Ecological Indicator Guilds (EIGs) from a large set of Ecological Indicator (EI) Systems. The ecological indicator criteria that were developed for this project and initially identified in our proposal are found in Figure 5-2).

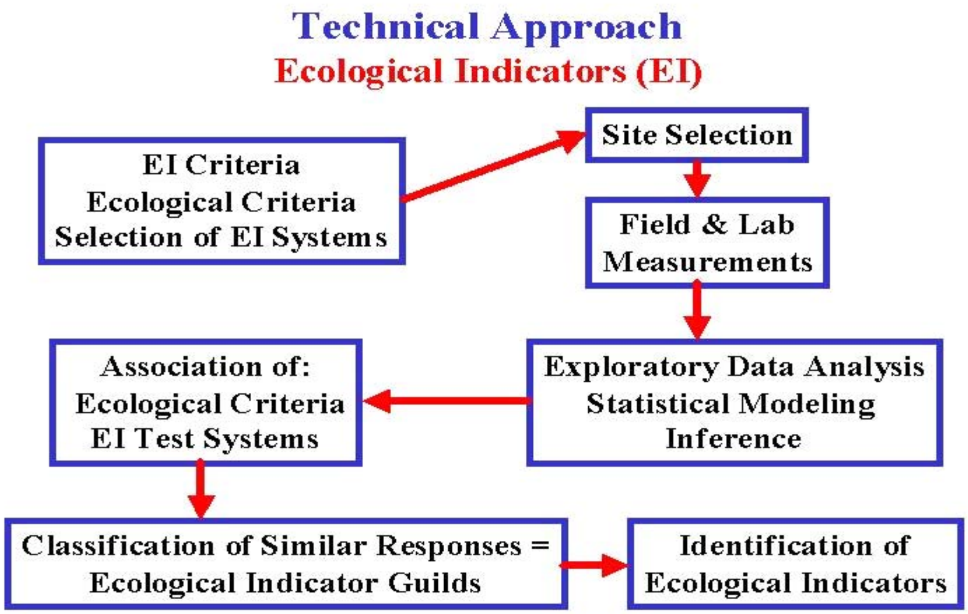


Figure 5-1. Technical approach for the identification of Ecological Indicators.

- Ease of use for land managers
- Cost effective
- Ecological relevance & value
- Reflect ecosystem dynamics and physiological stress
- Quantifiable with statistical estimates of accuracy & precision
- Robust & multi-scale
- EcoRegion application
- Global methodology extension
- Symmetry: track degradation & recovery/restoration
- Reasonable response times
- Reliable, consistent, unambiguous
- Incorporation of natural variance
- Known sensitivity to temporal sampling window
- Association with suites of stressors

Figure 5-2. Ecological Indicator Design Criteria.

5.3 Phase I Research Summary

Research was conducted on nine research sites in the Fall Line Sandhills at Fort Benning, Georgia. All sites were located in adjacent watersheds and possessed very similar physiography (upland sandhills), vegetation (mixed pine-hardwood forest), soils (sandy loam), and history (pre-1940s agriculture). Three sites each were classified into High, Medium, and Low disjunct disturbance classes (Figure 5-3, Figure 5-4, and Figure 5-5).

H3

H1

Figure 5-3. High disturbance – current mechanized infantry training activities.

M3

M1

Figure 5-4. Medium disturbance – past training activities and current foot traffic.

L2

L1

Figure 5-5. Low disturbance – no military vehicles and minimal foot traffic.

High sites were characterized by current extensive mechanized infantry training activities employing tracked and wheeled tactical vehicles, foot soldiers, bivouacs, and associated support elements. Medium sites experienced past military training activities, but are currently used primarily by foot soldiers. Low sites show no evidence of mechanized military training activities, and experience only light foot traffic. Over 100 Ecological Indicator Systems in six general ecological categories were considered. Thirty-two were selected for field evaluation in 2000 through 2002, and six were identified as promising for validation in Phase II research (Table 5-1).

Table 5-1. Selection of Ecological Indicator Systems for field evaluation from six general ecological classes.

EIS Class	Reviewed	Field Tested	Promising
Terrestrial Plants, Habitat Metrics	23	14	2
Terrestrial Animals	21	11	1
Soils & Microbial	29	5	3
Aqu./Rip. Animals	10	2	0
Aquatic Plants	0	0	---
Hydrology, Abiotic Aquatic	20	0	---
TOTAL	103	32	6*
Est. number of all variables in EIS	2060	320	60
* Note that six Ecological Indicator Systems were identified as promising based on the results of discriminant analysis.			

Discriminant Analysis was used on the selected EI Systems to extract a reduced subset of weighed variables for each EI System that maximized the separation of the three disturbance classes in multivariate space. Therefore, EIGs are classes of Ecological Indicator System variables expressing a similar response to disjunct land-use disturbance classes. In our research design, guilds represented suites of environmental variables or species groups explicitly characterizing the landscape disturbance gradient. Table 5-2 lists the six identified EIGs.

Table 5-2. Development of Ecological Indicator Guilds (EIGs) from Ecological Indicator Systems using discriminant analysis.

Note the significant reduction in the number of variables for most analyses.

Ecological Indicator System	Original Number of Variables	Ecological Indicator Guild[1]
Habitat Characterization (physiognomy and soil physical properties)	23	2
Ground Cover (floristics)	126	9
Ground Ant Communities	48	6
Microbial Communities[2]	5	5
Soil Chemistry[3]	5	3
Nutrient Dynamics & Leakage	12	7

[1]Number of minimum variables extracted by discriminant analysis capable of distinguishing the three disturbance classes.

[2]The Microbial Communities EIS requires additional analysis using individual substrate microbial functional responses. The current analysis was carried out using "Total Activity" and "Substrate Utilization Diversity" for both bacteria and fungi.

[3]The Soil Chemistry EIG led to the development of an Ecological Indicator based on "Soil Mineralization Potential" that was independent of the discriminant analysis.

Soil A-Horizon Depth and Soil Compaction were identified as not only the most important components of the Habitat EI System, but they also possessed more discriminating power than any of the other derived Ecological Indicators. The first Discriminant Function (DF1) of the Habitat EIG, heavily weighed by these two variables, effectively separated the three disturbance classes in discriminant space (Figure 5-6).

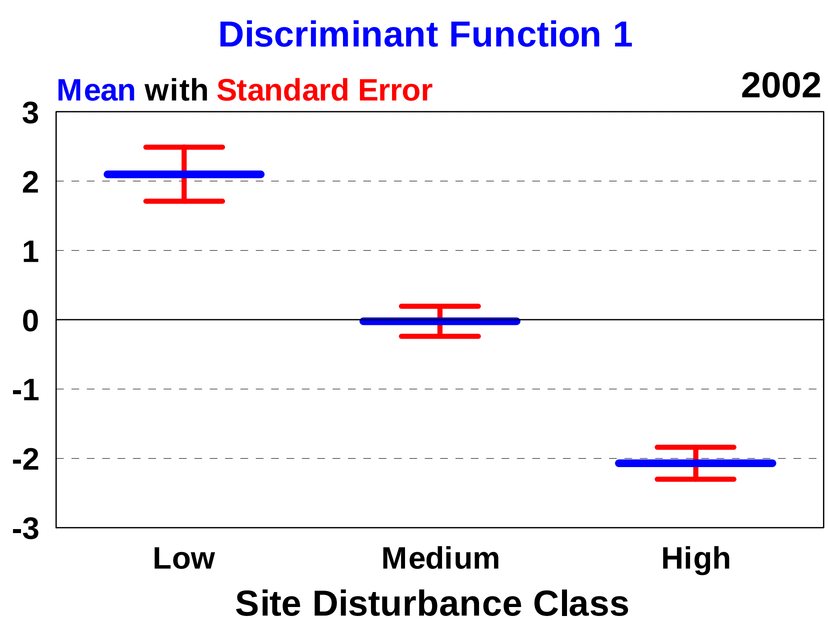


Figure 5-6. Discriminant Analysis: 15 habitat variables.

Discriminant Function 1 dominated by A-horizon depth and soil compaction.

The Ground Ant Communities were also important in distinguishing among the three disturbance classes. However, in this case DF1 and DF2 were both required for the complete discrimination (Figure 5-7). DF1 separated the High sites from the less disturbed sites, and DF2 separated Low from Medium sites. Six species were important in the discrimination. *Dorymyrmex smithi* was highly negatively correlated with DF1, while *Paratrechina parvula* and *Aphaenogaster floridana* were highly positively correlated. In the case of DF2, *Leptothorax texana* was highly positively correlated, while *Camponotus castaneus* and *Solenopsis molesta* were highly negatively correlated. The discriminant analysis clearly illuminated the relationship between habitat disturbance and ant species community composition. *D. smithi* was a dominant species (87% of individuals) and strongly characteristic of the High disturbance sites. Nevertheless, when this species was excluded from discriminant analysis, the results did not differ substantially. This was due to the two species in DF1 that were associated with less disturbed sites contributing more significantly to discriminant scores when *D. smithi* was removed. Of course, the removal of the dominant did not affect DF2, because of its low contribution to this axis.

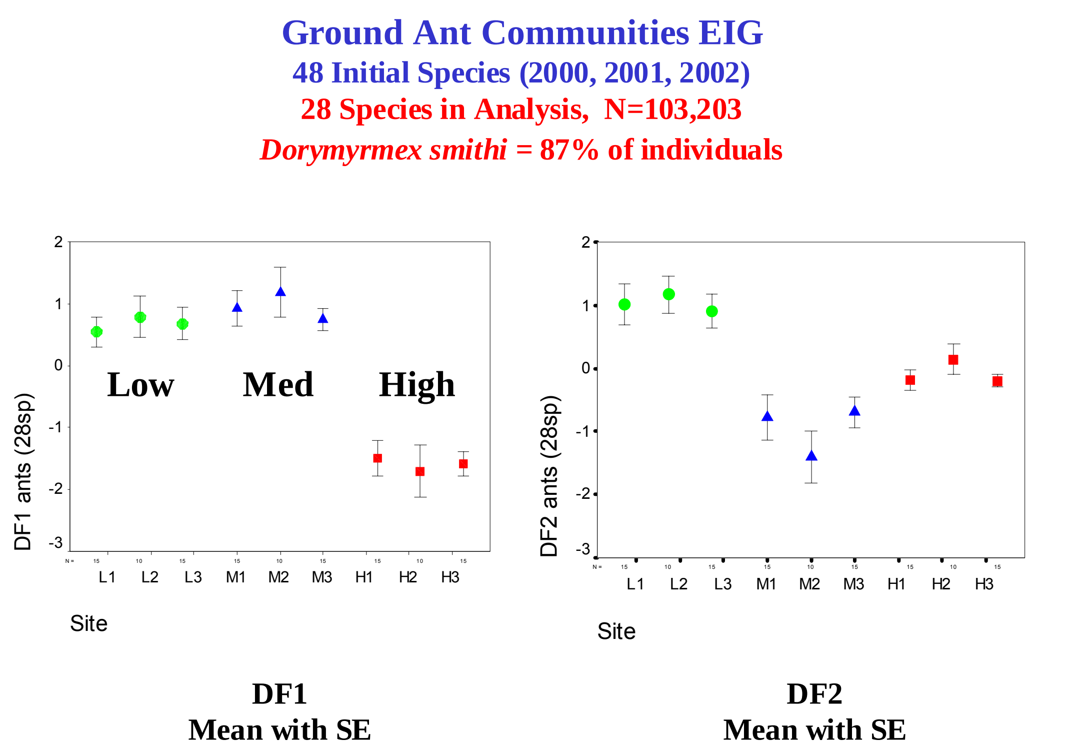


Figure 5-7. Discriminant analysis results of Ground Ant Communities EIG System with 28 species in the analysis.

Rare species (N=20) were excluded from the analysis. Six species were important in the discriminate analysis.

Soil Mineralization Potential appears to be an important Ecological Indicator derived from the Soil Chemistry EI System independently from discriminant analysis (Figure 5-8). Note that ammonium (NH_4) characterizes Low disturbance sites, while High sites are characterized by nitrate (NO_3). Medium sites were intermediate in their ammonium/nitrate ratio. This Ecological Indicator suggested that the M2 site was the most disturbed Medium site.

All field data collected between 2000 and 2002 at the nine original sites are still being analyzed and modeled for discovering additional interrelationships. This is particularly relevant for the Microbial Communities EI System.

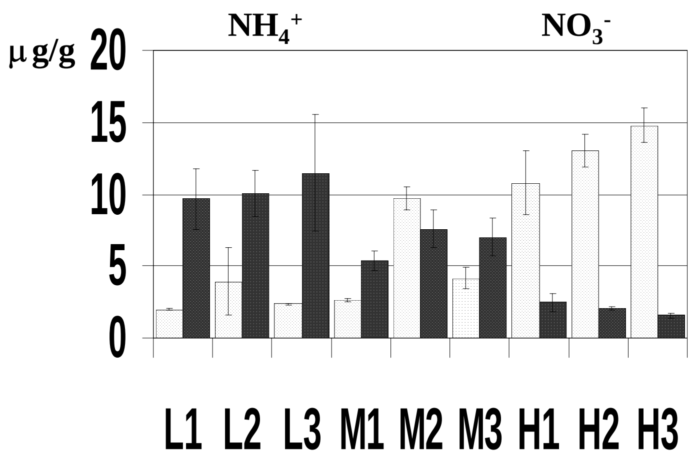


Figure 5-8. Soil Mineralization Potential for soil samples incubated in the laboratory for 4 weeks.

5.4 Phase II: Validation of Ecological Indicator Guilds, Initial Results

Forty research sites were selected in April through May 2003, including the original nine, to represent the full range of upland habitats at Fort Benning: levels of military training disturbance, upland forest community types, and Fort Benning's "Unique Ecological Areas." The selection of these sites was based on eight GIS databases, site criteria and data from other SEMP research teams, and extensive field ground-truthing. Four perpendicular 100-m long transects with a random orientation were centered on each site. Plot size was 4-hectares. Field data were collected in a systematic-random design along each transect. Each of the 40 sites were ranked in the field by visually assessing habitat disturbance related to military training activities on an ordinal scale of 1 to 10. For consistency, the same individual (Team PI) did all the rankings, and rankings were conducted before field data were collected. The most pristine habitats were rated "1", while "10" indicated the most severely degraded. Field data were collected on the following Ecological Indicator Guilds: (1) Habitat Characterization (physiognomy and soil physical properties), (2) Ground Cover (floristics), (3) Ground Ant Communities, (4) Microbial Communities, (5) Soil Chemistry (including soil mineralization potential), and (6) Developmental Instability of the perennial forb Tred-Softly (*Cnidoscolus stimulosus*).

The 40 sites were classified into upland forest community types on the basis of tree species basal areas, using Hierarchical Agglomerative Cluster Analysis employing Ward's criterion and squared Euclidian distance as the similarity metric. This procedure has desirable properties. Independently, Nonmetric Multidimensional Scaling (NMS) ordination was also performed on the tree species basal area data to disclose potential environmental gradients in the research sites, and to graphically display the results of the Cluster Analysis (Figure 5-9).

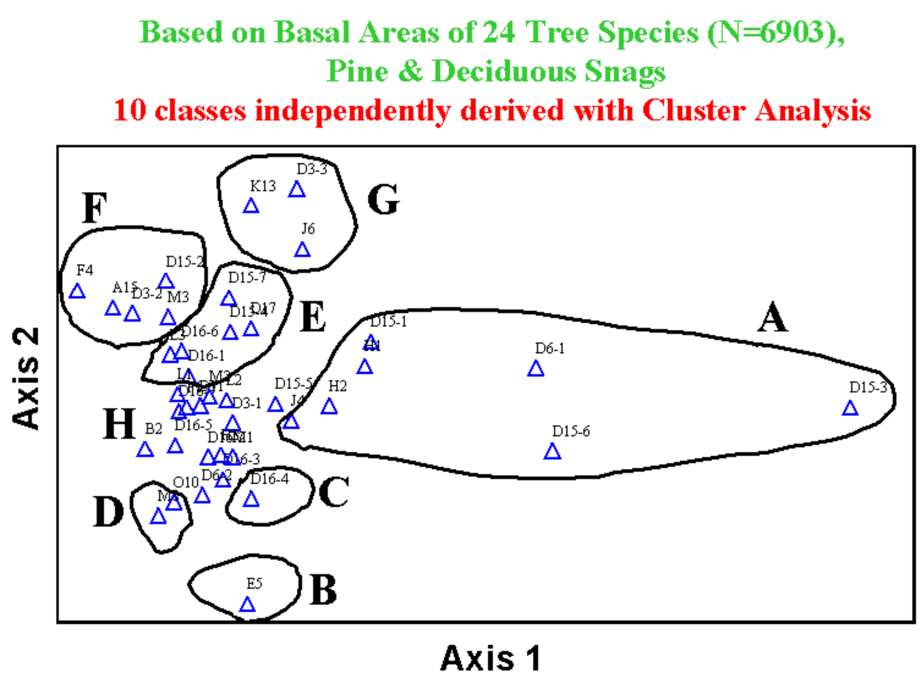


Figure 5-9. NMS ordination of 40 sites.

<u>10 Forest Communities Extracted with Cluster Analysis (N)</u>

A: Highly Disturbed Training Areas (7)
B: Oak-Hickory Mesic Deciduous Forest (1)
C: White/Southern Red/Post Oak – Shortleaf/Loblolly Forest (1)
D: Piedmont Loblolly Pine Forests (2)
E: Longleaf Pine – Oak Forests (6)
F: Longleaf Pine Forests (5)
G: Xeric Scrub Oak – Pine Savannas (3)
H: Pine – Hardwoods Mixed Forests:
Loblolly/Shortleaf – Hardwoods (6)
Mixed Pine – Oak – Hickory (7)
Mixed Pine – Southern Red Oak (2)

Ten forest communities were identified with cluster analysis. This result was used to delineate 7 forest communities in the NMS ordination of the 40 sites. Note that three pine-hardwoods mixed forests (H) were closely clustered in the ordination. The first NMS axis represents a long gradient in basal area, clearly separating the highly disturbed sites (A) with low basal areas from the mature stands of Longleaf Pine Forests (F) on opposite ends of this gradient. The second axis represents a landscape moisture gradient, ranging from the Oak-Hickory Mesic Deciduous Forest (B) to Xeric Scrub Oak – Pine Savannas (G).

Soil A-Horizon Depth (cm) and Soil Compaction (Lang units) variables were each scaled such that the site with the deepest A-horizon or least compacted soil was scored a "100," while the other sites were scaled proportionately. The "Soil Ecological Indicator" was simply the sum of these two scaled variables divided by two. One-way Analysis of Variance (ANOVA) was used to test the significance of habitat, soil chemistry, and microbial variables among the 10 ordinal disturbance classes. Table 5-3 presents the ANOVA results of Habitat, Soil Chemistry, and Microbial variables with Disturbance Class as the treatment. Note that when all 10 Disturbance Classes were used, all Habitat variables, Ammonium (but especially the NH_4/NO_3 ratio), Soil Organic Content, and Bacteria Functional Diversity were significantly different among the Disturbance Classes. This was primarily attributed to the High disturbance sites, because when these were excluded from the ANOVA analysis, only Soil Ecological Indicator, Soil Compaction, and the NH4/NO3 ratio were significantly different among the remaining 31 Low and Medium sites. There was no significant difference among Low and Low/Med sites (N=18) for any of the variables examined.

Table 5-3. One-Way ANOVA results of Habitat, Soil Chemistry, and Microbial variables with Disturbance Class as treatment.

NS indicates NOT SIGNIFICANT values of P. MBC = Microbial Biomass Carbon, FTA = Fungal Total Activity, FFD = Fungal Functional Diversity, BTA = Bacteria Total Activity, BFD = Bacteria Functional Diversity.

Disturbance Classes	**All Sites 1 – 10 (N=40)**	**Low - Medium Sites 1 – 7 (N=31)**	**Low, Low/Med Sites 1 – 4 (N=18)**
Variable			
Soil Ecological Indicator	<0.001	0.006	0.16 NS
A-Horizon Depth	0.002	0.075 NS	0.60 NS
Soil Compaction	<0.001	0.009	0.085 NS
Canopy Cover	<0.001	0.098 NS	0.057 NS
Basal Area	<0.001	0.18 NS	0.30 NS
Tree Density	<0.001	0.20 NS	0.16 NS
Nitrate (NO_3)	0.57 NS	0.51 NS	0.77 NS
Ammonium (NH_4)	0.014	0.028	0.39 NS
NH_4/NO_3	<0.001	<0.001	0.68 NS
Organic Content	0.012	0.11 NS	0.11 NS
pH	0.85 NS	0.78 NS	0.62 NS
MBC	0.11 NS	0.14 NS	0.16 NS
FTA	0.89 NS	0.59 NS	0.50 NS
FFD	0.34 NS	0.33 NS	0.20 NS
BTA	0.36 NS	0.84 NS	0.71 NS
BFD	0.008	0.58 NS	0.79 NS

The environmental variables that were significant in the ANOVA results were plotted against the 10 disturbance classes: Soil Properties (Figure 5-10), Canopy Cover (Figure 5-11), Basal Area (Figure 5-12), NH4/NO3 ratio (Figure 5-13), Soil Organic Content (Figure 5-14) Bacteria Functional Diversity (Figure 5-15).

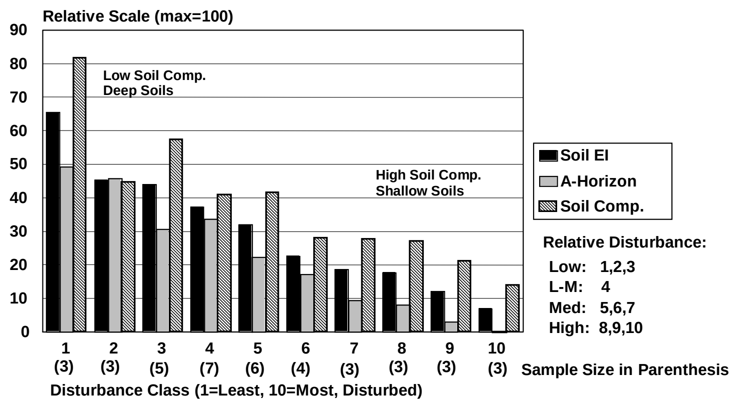


Figure 5-10. Soil variables.

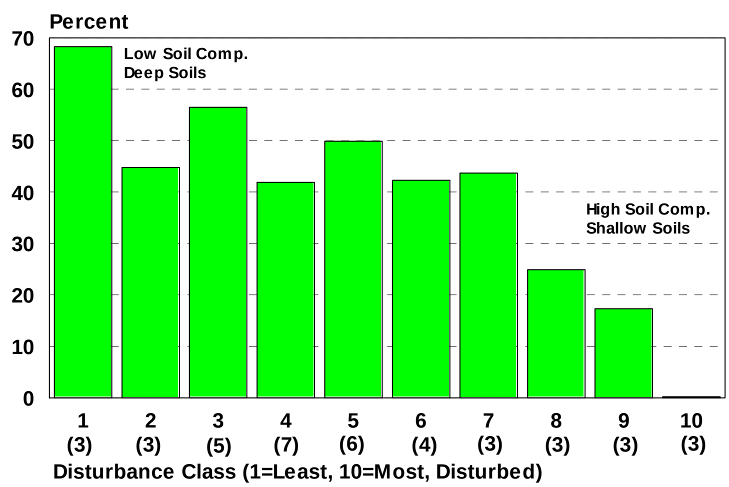


Figure 5-11. Canopy cover.

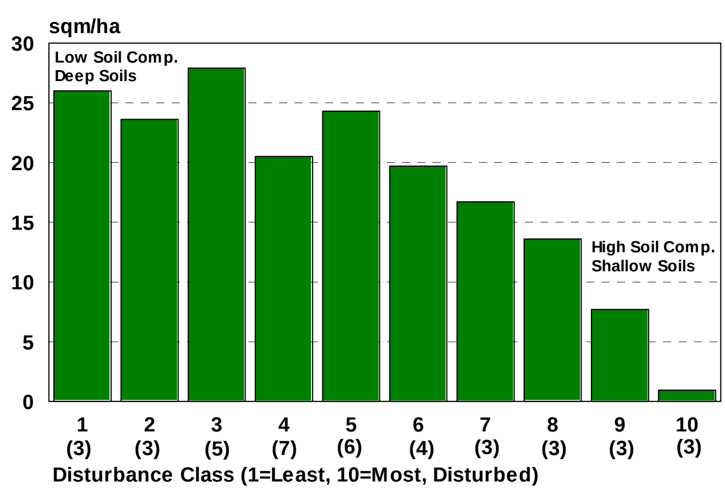


Figure 5-12. Basal area.

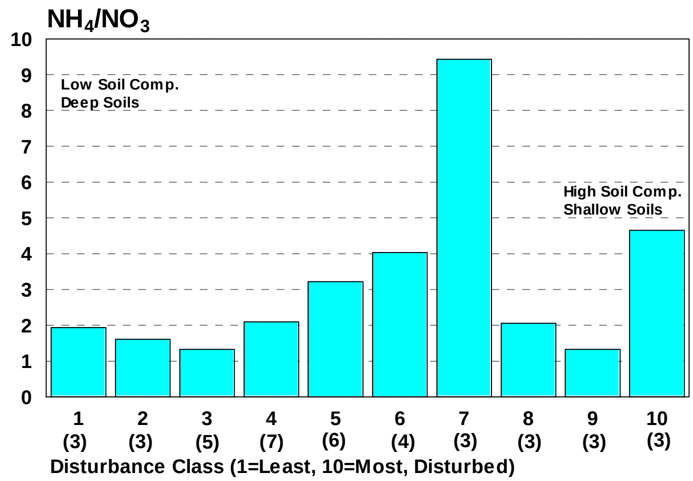


Figure 5-13. Ammonium-Nitrate ratio.

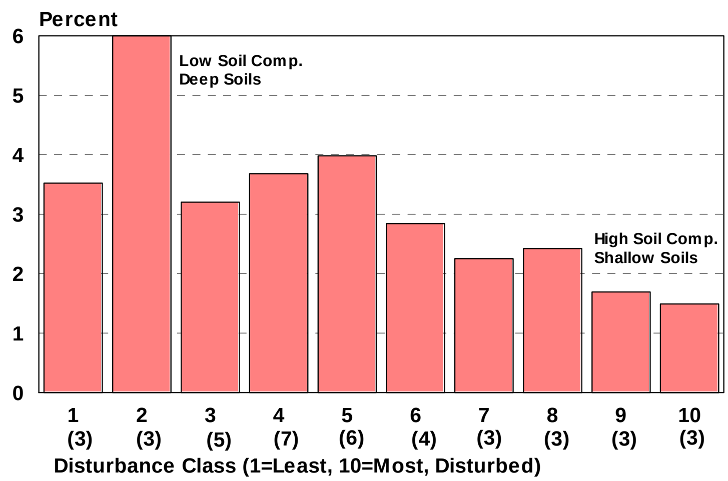


Figure 5-14. Soil organic content.

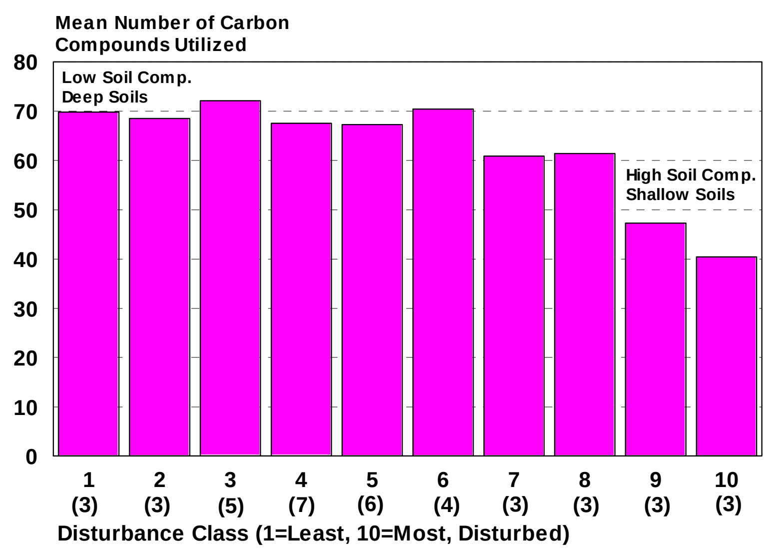


Figure 5-15. Bacterial function diversity.

The “Soil Ecological Indicator” (SEI) derived here appears to be a reliable and robust indicator of landscape condition — from relatively pristine mesic deciduous forests and xeric scrub oak-pine savannas to very severely disturbed military training landscapes. The SEI clearly “predicted” the continuous disturbance gradient represented by the 10 ordinal disturbance classes (Figure 5-10, Spearman’s rho two-tailed nonparametric rank bivariate correlation, -0.85, $P<0.001$). With the exception of the discrepancy between disturbance classes (DC) 3 and 4, A-Horizon Depth also closely followed the disturbance gradient. Soil Compaction, in general, followed the disturbance gradient, but there were a number of deviations. DC-2 sites were “too compacted” contrasted to DC-3, DCs 4 and 5 were similar, as were DCs 6, 7, and 8. The observed “discrepancy” could be attributed to soil texture, specifically clay content. Clayey soils tend to display more compaction at any given level of disturbance. This is currently being analyzed. Future “adjustments” to this base SEI metric will include corrections for soil texture, particularly clay content. Importantly, the SEI is practical and economical to measure and derive, possesses biological interpretation, and has direct and obvious strong relationships to ecological processes.

Based on our current state of analysis, the five other environmental variables evaluated along this disturbance gradient (Figure 5-11 through Figure 5-15), were not effective at tracking landscape degradation, unless the disturbance was very severe. However, Basal Area showed a reasonably consistent declining trend from the Medium sites (DC-5) to the most severely disturbed sites (DC-10). A great deal of additional data analysis and further multivariate modeling remains before the data from these 40 sites are fully evaluated and understood.

Ant Communities: Additional Phase I Results

Ant diversity and abundance was assessed among the nine sites. Because measures of diversity and abundance are often highly correlated, we used a principal components analysis to reduce five correlated variables to a smaller number of uncorrelated variables. The first principal component (PC1) contrasted sites with high species diversity, high equitability, and small numbers with sites having low species diversity, low equitability, and large numbers (Table 5-4).

Figure 5-16 shows species abundance curves for the Ant Communities. This graphic clearly demonstrates the lack of equitability at the highly disturbed sites.

Table 5-4. Principal components analysis of diversity and abundance indices based upon pitfall and arboreal samples (2000-2002).

Values are the loadings on the first two principal components (PC1 and PC2).

	Pitfall Traps		Sweeps		Arboreal	
Variables	**PC1**	**PC2**	**PC1**	**PC2**	**PC1**	**PC2**
Number of species (S)	**0.805**	0.488	**0.866**	0.323	**0.890**	0.192
Number of individuals (N)	-0.670	**0.658**	-0.235	**0.954**	-0.344	**0.916**
Simpson's Index (D)	**-0.931**	0.145	**-0.948**	-0.080	**-0.931**	-0.181
Shannon-Weiner Index (H')	**0.961**	-0.046	**0.955**	0.150	**0.960**	-0.193
Species Richness	**0.940**	0.242	**0.852**	-0.322	**0.838**	-0.248
Percent of Variance	75.21	15.05	66.83	22.96	68.00	20.15

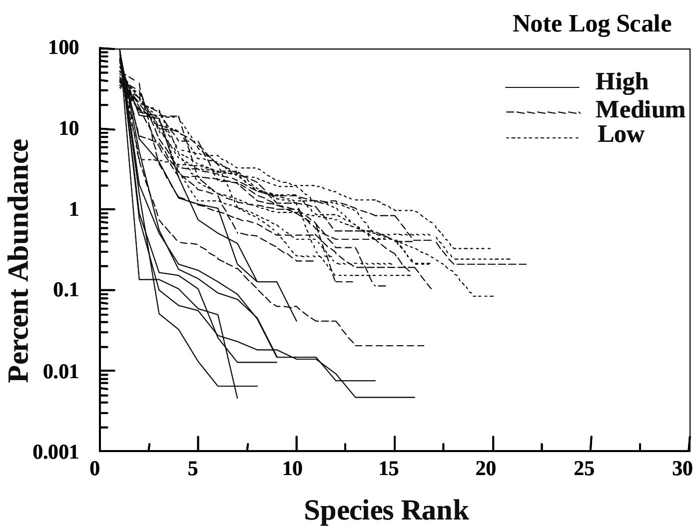


Figure 5-16. Species abundance curves for ants in pitfall traps (2000-2002).

Each curve represents a site in a particular year.

We used canonical correspondence analysis (CCA) to elucidate ant community species composition with environmental variables. CCA is a reciprocal averaging (matrix rows-columns weighted averages) constrained ordination technique, that ordinates sampling sites in two or three dimensions based on their multi-dimensional complex species composition patterns. Ordinations and their axes are a large family of variable reduction methods, where fewer dimensions are derived that optimally summarize large variable sets. In CCA the ordination is constrained because it involves the addition of multiple least squares regression of species distributions onto environmental variables. The environmental variables are represented in ordination space as vectors. The directions of vectors represent the directions of largest changes in the variables they represent. The length of the vector indicates the relative importance of an environmental variable relative to species distributions. For direct interpretation, the cosine of the angle between the vector and an axis is equal to the correlation coefficient between that environmental variable and the axis. Each axis represents a unique combination of species compositions. Figure 5-17 is a CCA biplot showing the sites as triangles and arrows as environmental variables. The ordination space represents ant species community compositions. The right side of the ordination clearly separates the three High sites from the Low and Medium sites on the left side. Note that the High sites were associated with two environmental variables, bare (bare ground), and lang (soil compaction). Ant communities were relatively similar to one another at Low and Medium sites. Low especially, but also Medium sites, were characterized by soildep (soil A-horizon depth), woody (% woody ground cover), Ntrees (tree density), four measures of tree basal area (BasalArea, NBA40, NBA20, NBA10), dbh (mean diameter breast height of trees), forbs (% forb ground cover), and grass (% grass ground cover). Soil shear strength (shear) was not an informative variable.

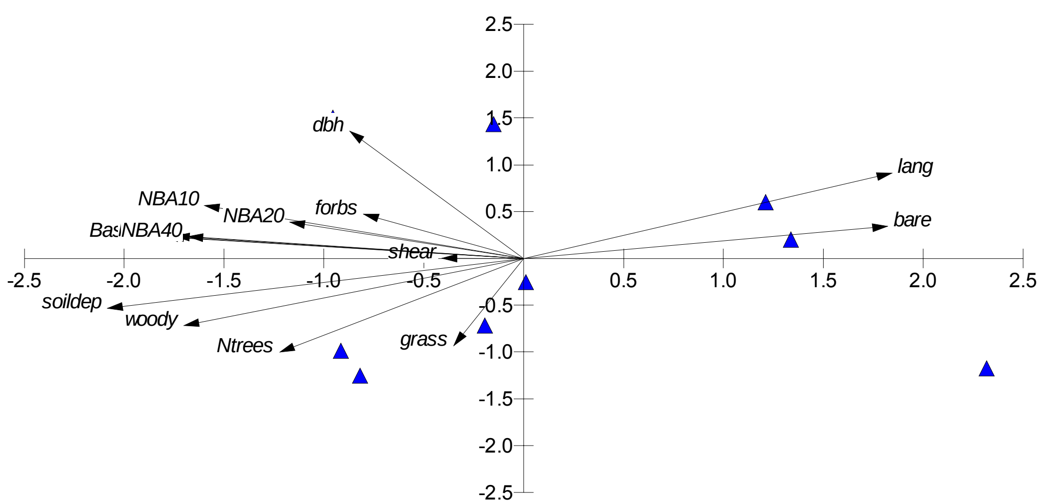


Figure 5-17. Canonical Correspondence Analysis of ant pitfall samples in 2002.

Filled triangles are sites; arrows represent environmental variables in ordination space of of ant community species compositions.

5.5 Plant Physiological Responses: Phase I Results

Fire has a profound effect on both developmental instability and photosynthesis. Net photosynthesis increased with disturbance if sites were burned the previous year for *Rhus copallinum* (Figure 5-18) and *Ipomoea pandurata* (Figure 5-19), and developmental instability increased with disturbance and burning for *Rhus* (Figure 5-20).

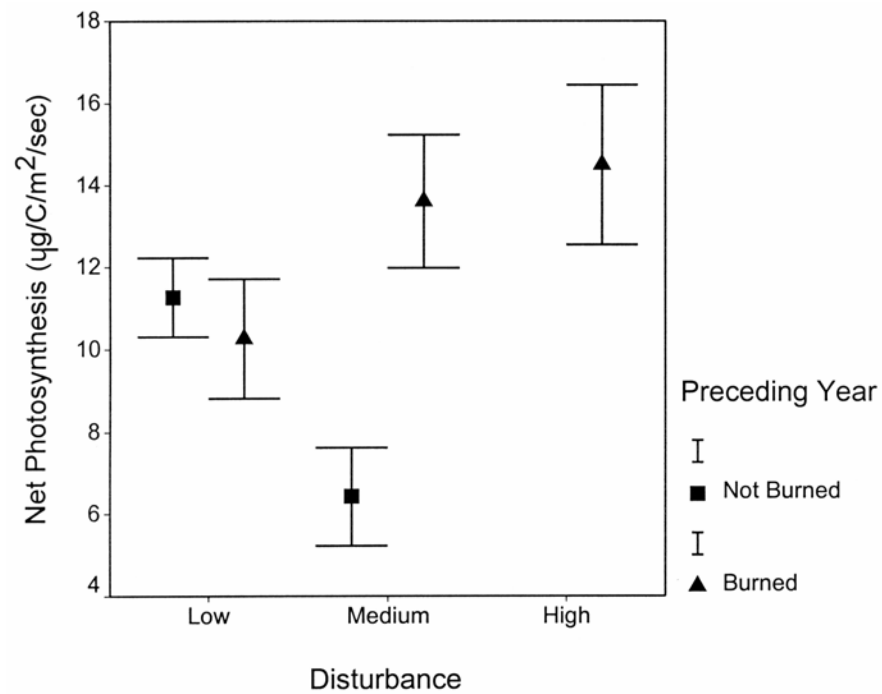


Figure 5-18. Net photosynthesis for *Rhus copallinum* increased with disturbance and burning.

Error bars represent 95% confidence intervals.

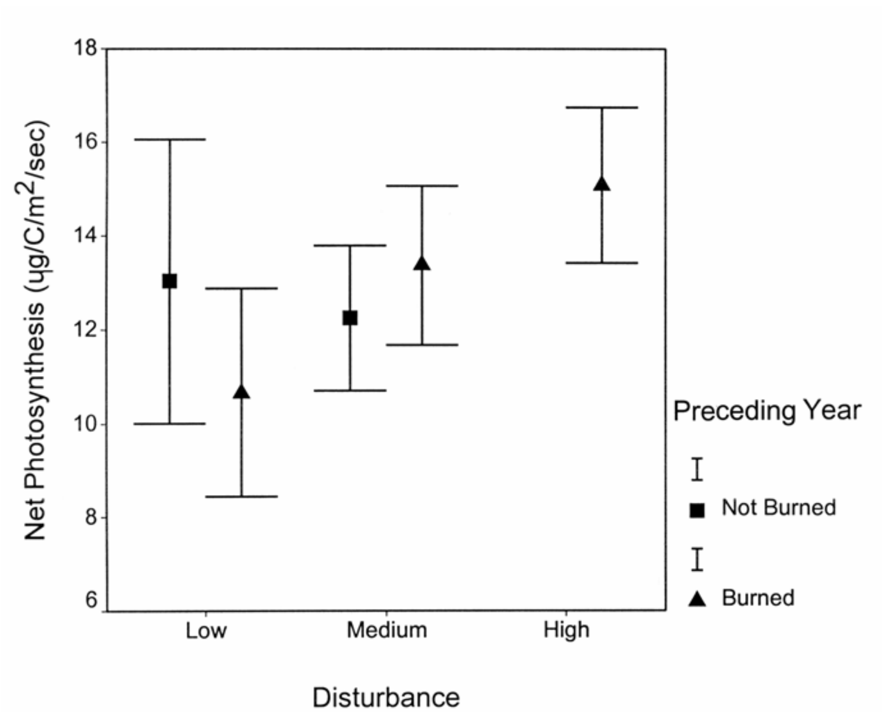


Figure 5-19. Net photosynthesis for *Ipomoea pandurata* increased with disturbance and burning.

Error bars represent 95% confidence intervals.

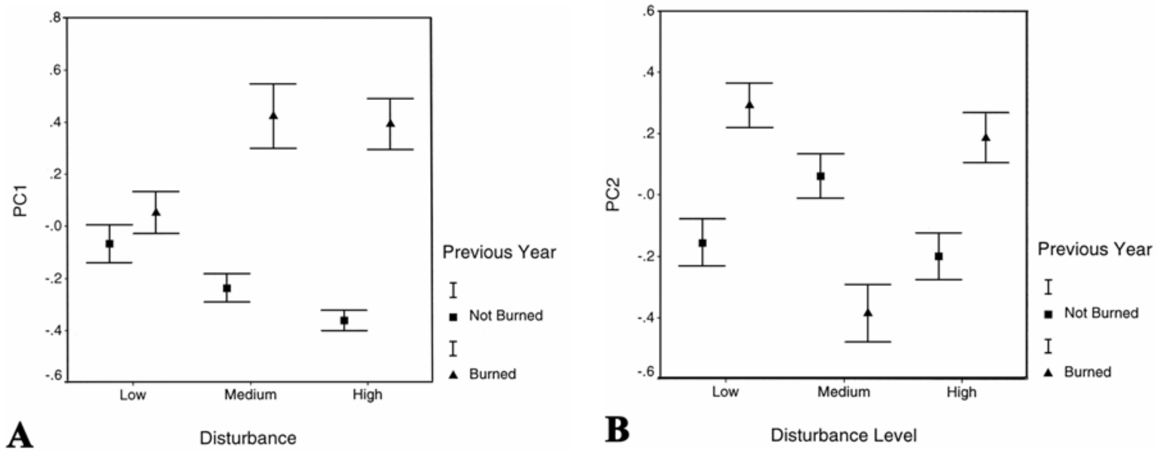


Figure 5-20. Developmental instability increased with disturbance and burning for *Rhus*. Error bars represent 95% confidence intervals.

In Figure 5-20(A) PC1 reflects the magnitude of developmental instability as all variables had positive loading scores. Note that PC1 increases with disturbance when sites have burned the previous year. PC2 [Figure 5-20(B)] reflects the pattern of developmental instability across the main vein. This type of asymmetry peaked at Medium disturbance sites in the absence of burning. Burning clearly alleviated this stress at these sites and altered the pattern of developmental instability.

Transpiration decreases with burning for *Rhus copallinum* (Figure 5-21).

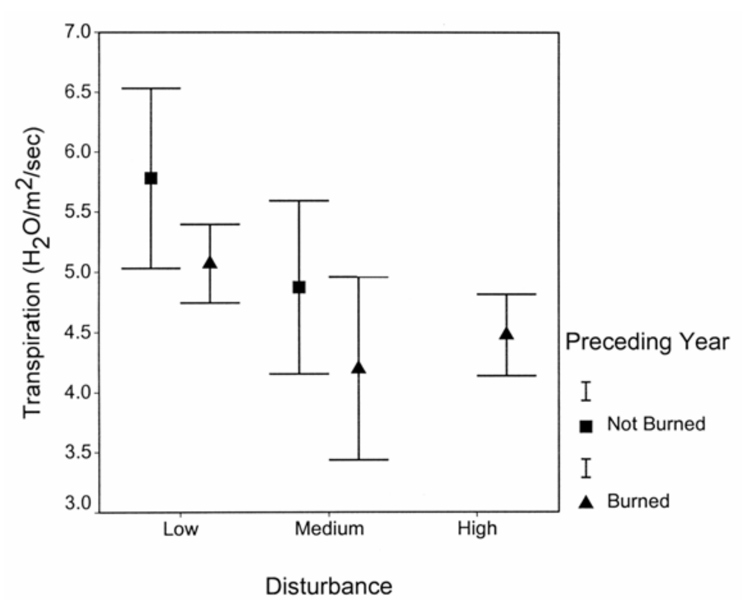


Figure 5-21. Transpiration of *Rhus copallinum* decreased with burning. Error bars represent 95% confidence intervals.

Cnidoscolus stimulosus appears to be the best indicator of disturbance as the magnitude of developmental instability reflected in PC1 increased with disturbance in both years for which we have data (Figure 5-22). Additionally, it appears to be unaffected by fire.

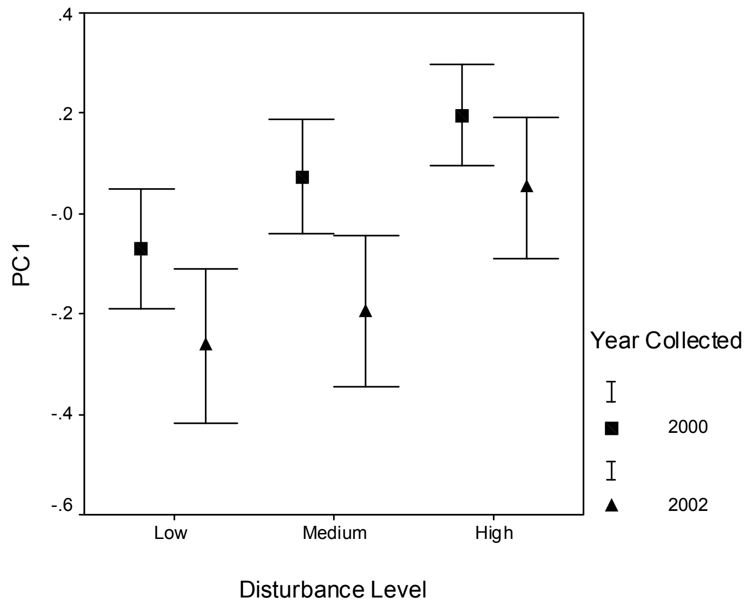


Figure 5-22. PC1 reflects the magnitude of developmental instability and increased with disturbance, whether or not a site was burned.

Burning clearly reduced developmental instability at all disturbance levels.
Error bars represent 95% confidence intervals.

5.6 Presentations During This Activity Period

Presentations

Effects of habitat disturbance on diversity and abundance of ants in the Southeastern Fall-Line Sandhills. Graham, J.H., H.H. Hughie, S. Roth, K. Wrinn, A.J. Krzysik, J.J. Duda, D.C. Freeman, J.M. Emlen, D.A. Kovacic, J.C. Zak. Presentation, Ecological Society of America Annual Meeting, August 2003, Savannah, GA.

Soil mineralization potential as an indicator of ecological disturbance. Kovacic, D.A., A.J. Krzysik, M.P. Wallace, J.J. Duda, D.C. Freeman, J.H. Graham, J.C. Zak, and H.E. Balbach. Presentation, Ecological Society of America Annual Meeting, August 2003, Savannah, GA.

Robust multivariate approaches for developing ecological indicators to classify landscapes on a military disturbance gradient. Krzysik, A.J., D.A. Kovacic, M.P. Wallace, J.H. Graham, J.C. Zak, J.J. Duda, J.M. Emlen, D.C. Freeman, and H.E. Balbach. Presentation, Ecological Society of America Annual Meeting, August 2003, Savannah, GA.

Understanding microbial and nutrient dynamics in forested ecosystems at Ft. Benning, GA: Implications to management strategies. Zak, J., E. Sobek, A. Krzysik, D. Kovacic, M. Wallace, J. Dudda, J. Emlen, C. Freeman, J. Graham, and H. Balbach. Presentation,

American Society of Agronomy Annual Meeting, November 2003, Denver, CO.

Impacts of disturbance severity on microbial and nutrient dynamics in forested areas at Ft. Benning, GA. Zak, J.C., E.A. Sobek, A. Nagy, H. Grizzle, A. Krzysik. Presentation, Soil Ecology Society Biannual Meeting, May 2003, Palm Springs, CA.

Posters

Integration of Ecological Indicators. Dale, V., A. Peacock, A. Wolfe, J. Fehmi, R. Addington, B. Collins, C. Garten, T. Greene, A. Krzysik, R. Larimore, M. Mulligan, J. Prenger, and P. Swiderek. SERDP Symposium, December 2003, Washington, D.C.

Effects of military-training activities on spider communities of the Fall-Line Sandhills at Fort Benning, Georgia. Graham, J.H., K. Wrinn, H.H. Hughie, J. Duda, D.C. Freeman, J.M. Emlen, H. Balbach, C. Chamberlin-Graham, and A.J. Krzysik. SERDP Symposium, December 2002, Washington, D.C.

Soil mineralization potential as an indicator of ecological disturbance. Kovacic, D.A., A.J. Krzysik, M.P. Wallace, H.E. Balbach, J.J. Duda, J.H. Graham, J.C. Zak, J.M. Emlen. SERDP Symposium, December 2003, Washington, D.C.

Development of ecological indicator guilds for land management: Characterizing ecosystem metrics along a disturbance gradient. Krzysik, A.J., J.H. Graham, D.A. Kovacic, J.C. Zak, H.E. Balbach, J.M. Emlen, and D.C. Freeman. SERDP Symposium, December 2002, Washington, D.C.

Development of ecological indicator guilds for land management: Initial validation of selected Ecological Indicators in diverse habitats. Krzysik, A.J., D.A. Kovacic, M.P. Wallace, J.C. Zak, H.E. Balbach, D.C. Freeman, J.J. Duda, J.H. Graham, and J.M. Emlen. SERDP Symposium, December 2003, Washington, D.C.

Effects of military-training activities on spider communities of the Fall-Line Sandhills at Fort Benning, Georgia. Wrinn, K., J.H. Graham, H.H. Hughie, J. Duda, D.C. Freeman, J.M. Emlen, H. Balbach, C. Chamberlin-Graham, and A.J. Krzysik. American Agronomy Society Annual Meeting, November 2002, Indianapolis, IN.

Manuscripts in Current Active Preparation

13 manuscripts in preparation

6 SEMP Ecological Indicators – 1114C

Annual Project Report

Project Year October 2002-September 2003 (FY03)

PI: Virginia H. Dale, Oak Ridge National Laboratory (ORNL)

Participants

Jack Feminella and Kelly Maloney, Department of Biological Sciences, Auburn University — Stream macroinvertebrates

Thomas Foster, Anthropology Department, Pennsylvania State University — Historical land cover

Patrick Mulholland, Environmental Sciences Division, Oak Ridge National Laboratory — Aquatic ecology

Latha Baskaran and Lisa Olsen, Environmental Sciences Division, Oak Ridge National Laboratory — Geographic information and landscape analysis

David White, Aaron Peacock, and James Cantu, Center for Environmental Technology, University of Tennessee — Soil microbiology

Virginia Dale and Daniel Druckenbrod, Environmental Sciences Division, Oak Ridge National Laboratory — Terrestrial and landscape indicators, integration

6.1 Executive Summary

The project is analyzing a suite of indicators that measure changes in ecological condition at different scales and for different media. The suite that we are examining includes measures of landscape patterns, soil microbial biomass and community composition, terrestrial understory and overstory, and conditions of stream chemistry and aquatic biology.

The landscape metrics for Fort Benning were calculated and analyzed from maps created from historical data and remote sensing imagery. An examination of land-cover class and landscape metrics indicated that a suite of metrics adequately describes the changing landscape at Fort Benning. The most appropriate metrics were percent cover, total edge (km), number of patches, descriptors of patch area, nearest neighbor distance, the mean perimeter-to-area ratio, clumpiness, and shape range index (which corrects for the size problem of the perimeter-to-area ration and thus is a measure of overall shape complexity).

An experiment was established in training compartment K-11 to examine how indicators change under experimental disturbances. Thinning and burning were done to constitute a "light" land use. The "heavy" treatment was implemented in May 2003 by a D7 bulldozer. Data on aquatic conditions, soil microbial biology, and understory indicators are being collected from the field experiment of disturbance impacts.

Early results for the short-term study show an initial loss of vegetation cover in June, but a rebound to cover levels equivalent to those found in the control plots by September. However, there are differences in the cover of plant species present before and after the treatments.

Potential aquatic indicators at Fort Benning have been narrowed to:

- Inorganic and total suspended sediment concentrations (either as baseflow or maximum storm increases),
- Baseflow phosphorus concentration,
- Baseflow dissolved organic carbon concentration,
- Baseflow pH,
- Organic matter content of stream bottom sediments, and
- Number of taxa in the aquatic orders Ephemeroptera, Plecoptera, and Trichoptera (EPT).

We are still evaluating whether storm-induced changes in ammonium and/or nitrate concentrations and diurnal changes in dissolved oxygen may be useful disturbance indicators. We are also evaluating sensitivity of (1) nationwide bioassessment protocols from the U.S. Environmental Protection Agency (USEPA, Rapid Bioassessment Protocols, RBPs), including richness, compositional, tolerance, and feeding group metrics, and (2) regional bioassessment protocols from North Carolina, Georgia, and Florida. Together, analyses of relationships between bioassessment metrics and disturbance intensity within SEMP catchments will allow us to evaluate the efficacy of a comprehensive set of protocols to indicate biotic impairment from sediment disturbance at Fort Benning.

We are monitoring the soil microbial community of the K-11 experimental area at Fort Benning. We are using the experimental conditions to examine our hypothesis that as a soil is remediated it does not escalate through states of succession in the same way as it descends following military use. We are exploring this hysteresis between disturbance and recovery process as a predictor of the resilience of the microbial community to repeated disturbance/recovery cycles. The soil samples have been collected before and after the treatments and are being analyzed.

We are also examining how roads can change the environmental conditions in which they occur at three spatial scales: a second-order catchment, a third-order watershed, and the entire military installation. At the finest resolution, total vegetation cover responded quickly to disturbance with a tracked vehicle, but there were differences in recovery between plant species. In examining roads within a watershed from 1974 to 1999, forest conversion was highest near unpaved roads and tank trails. At the level of the installation, major roads and unpaved roads and tank trails were associated with most of the conversion from forest to nonforest. These results lead to questions about appropriate metrics of road impacts.

Our progress in examining each type of indicator is discussed in separate sections below.

6.2 Vegetation Indicators

Daniel Druckenbrod and Virginia Dale, Oak Ridge National Laboratory

Our research on understory plants as indicators of ecological disturbance recorded substantial progress this year with the initiation of an experimental tracked-vehicle disturbance in the K11 watershed at Fort Benning. In May 2003, three, 50-m disturbance transects were created within a watershed at K11 at Fort Benning with the use of a D7 bulldozer that removed both extant vegetation cover and surface soil organic matter. Bob Larimore, Hugh Westbury, and Hal Balbach provided assistance in coordinating the use of this bulldozer. Vegetation surveys were conducted both shortly after the disturbance treatment in June and in September to begin capturing the temporal response in plant cover. Control transects were established parallel to the disturbance treatments at a distance of 5 m. Ten points were chosen at random along each treatment and control transect, for a total of 60 survey points, and plant cover was assessed using 0.568-m radial plots at each point. Plant cover was ranked according to a modified form of the Braun-Blanquet (1932) cover system (Dale et al. 2002). Species were identified according to Radford et al. (1968).[1]

[1] Braun-Blanquet, J. 1932. In: G. D. Fuller and H. S. Conard (eds.), Plant Sociology: the Study of Plant Communities, Authorized English translation of Pflanzensoziologie, McGraw-Hill, New York; Dale, V. H., S. C. Beyeler and B. Jackson. 2002. Understory vegetation indicators of anthropogenic disturbance in longleaf pine forests at Fort Benning, Georgia, USA. Ecological Indicators 1: 155-170; Radford, A. E., H. E. Ahles and C. R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. University of North Carolina Press, Chapel Hill.

Additionally during the September field effort, we continued our surveys of the long-term vegetation plots located within both of the paired K11 watersheds. These plots are surveyed to family and functional classification levels according to Raunkiaer's life-form classification system (Kershaw and Looney 1985).[2] Specimens of species collected from both the short-term experimental plots and these ongoing long-term plots were verified using the University of Tennessee Herbarium.

Early results for the short-term study show an initial loss of vegetation cover in June, but a rebound to cover levels equivalent to those found in the control plots by September. These results also suggest that the composition of the resulting plant cover differs from that of the control plots with a substantial increase in the presence of *Polypremum procumbens*. These results were presented in an invited symposium at the American Society of Agronomy Annual Meeting in Denver, Colorado on November 4, 2003. This military land- use symposium focused on the impacts of vehicular traffic in natural areas and the presentations from this conference are being submitted to the *Journal of Terramechanics* for a special issue in January 2004.

6.3 Stream Studies

P. J. Mulholland, Oak Ridge National Laboratory
Jack Feminella, and Kelly Maloney, Auburn University

6.3.1 Stream chemistry

We have finished all chemical analyses and have begun to analyze the data for the disturbance experiment in training compartment K-11. Preliminary analysis indicates there was no effect on the stream. We are also continuing to analyze the stream chemistry data collected in 2002 and 2003 to identify the most promising indicators for disturbance at the catchment scale. To date, the following stream chemistry parameters appear to be the strongest indicators: inorganic and total suspended sediment concentrations (either as baseflow or maximum storm increases), baseflow phosphorus concentration, baseflow dissolved organic carbon concentration, and baseflow pH (Figure 6-1). The organic matter content of stream bottom sediments continues to look like a strong disturbance indicator

[2] Kershaw, K. A., and J. H. Looney. 1985. Quantitative and Dynamic Plant Ecology. 3rd Ed. Arnold, London.

as well. We are still evaluating whether storm changes in ammonium and/or nitrate concentrations and diurnal changes in dissolved oxygen may be useful disturbance indicators.

6.3.2 Stream macroinvertebrates and fish

All benthic macroinvertebrates have been identified and enumerated, and resultant data files have been compiled into an Access® database. Perhaps the single best macroinvertebrate metric reflecting indicating disturbance was the number of taxa in the aquatic orders Ephemeroptera, Plecoptera, and Trichoptera (EPT). EPT richness was negatively correlated with disturbance intensity for all three sampling seasons (Figure 6-2) throughout the study, suggesting that catchment disturbance negatively affects species in these sensitive orders. In addition, we are currently evaluating sensitivity of (1) nationwide bioassessment protocols from the USEPA (Rapid Bioassessment Protocols, RBPs), including richness, compositional, tolerance, and feeding group metrics, and (2) regional bioassessment protocols from North Carolina, Georgia, and Florida. Together, analyses of relationships between bioassessment metrics and disturbance intensity within SEMP catchments will allow us to evaluate the efficacy of a comprehensive set of protocols to indicate biotic impairment from sediment disturbance at Fort Benning.

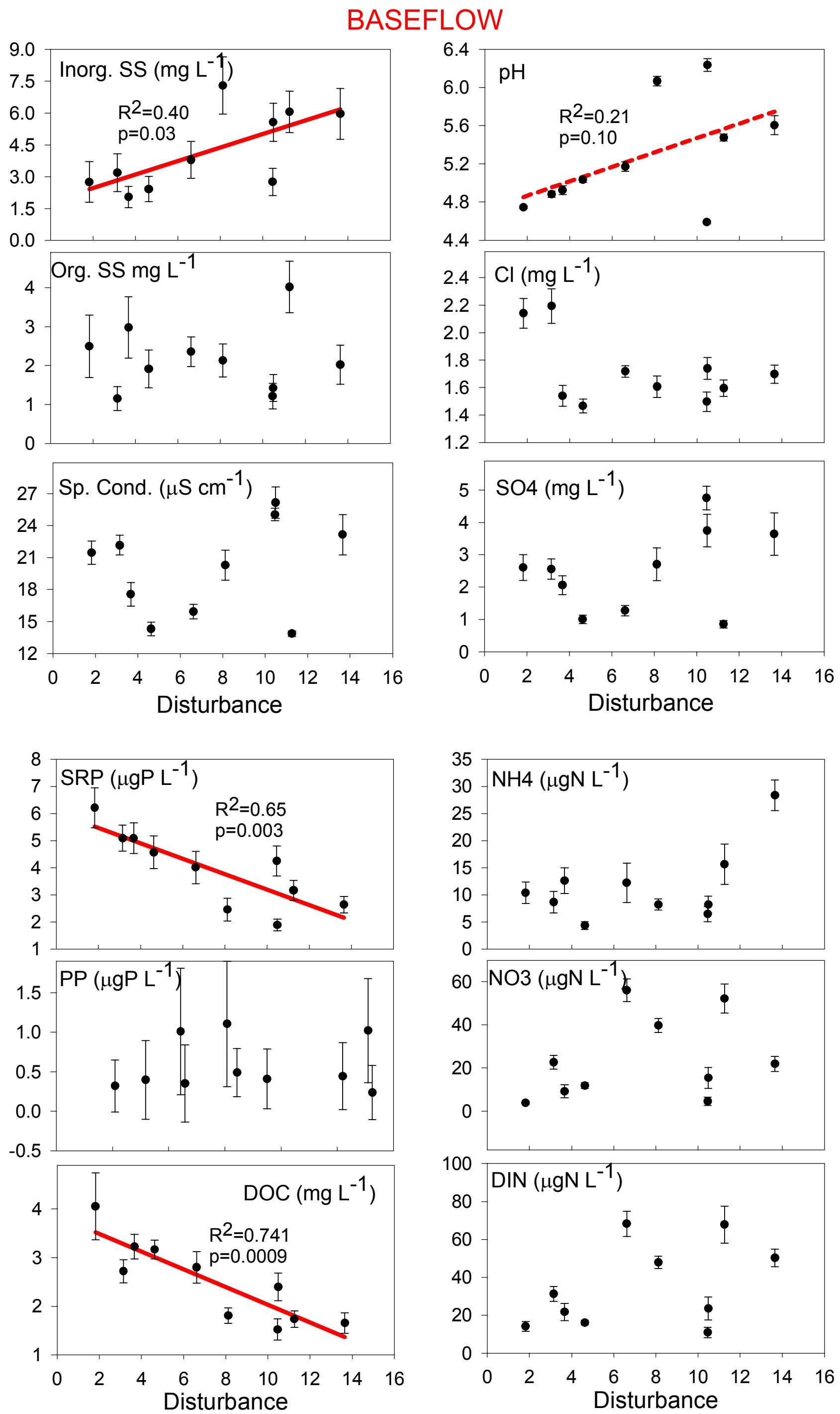


Figure 6-1. (DIN) plotted against catchment disturbance level.

The catchment disturbance level is defined as the fraction of the catchment consisting of bare ground on slopes > 3% and roads. Baseflow concentrations of inorganic suspended sediments, organic suspended sediments, specific conductance, pH, Cl, SO4, soluble reactive phosphorus (SRP), particulate P, dissolved organic carbon (DOC) NH4, NO3, and total dissolved inorganic nitrogen

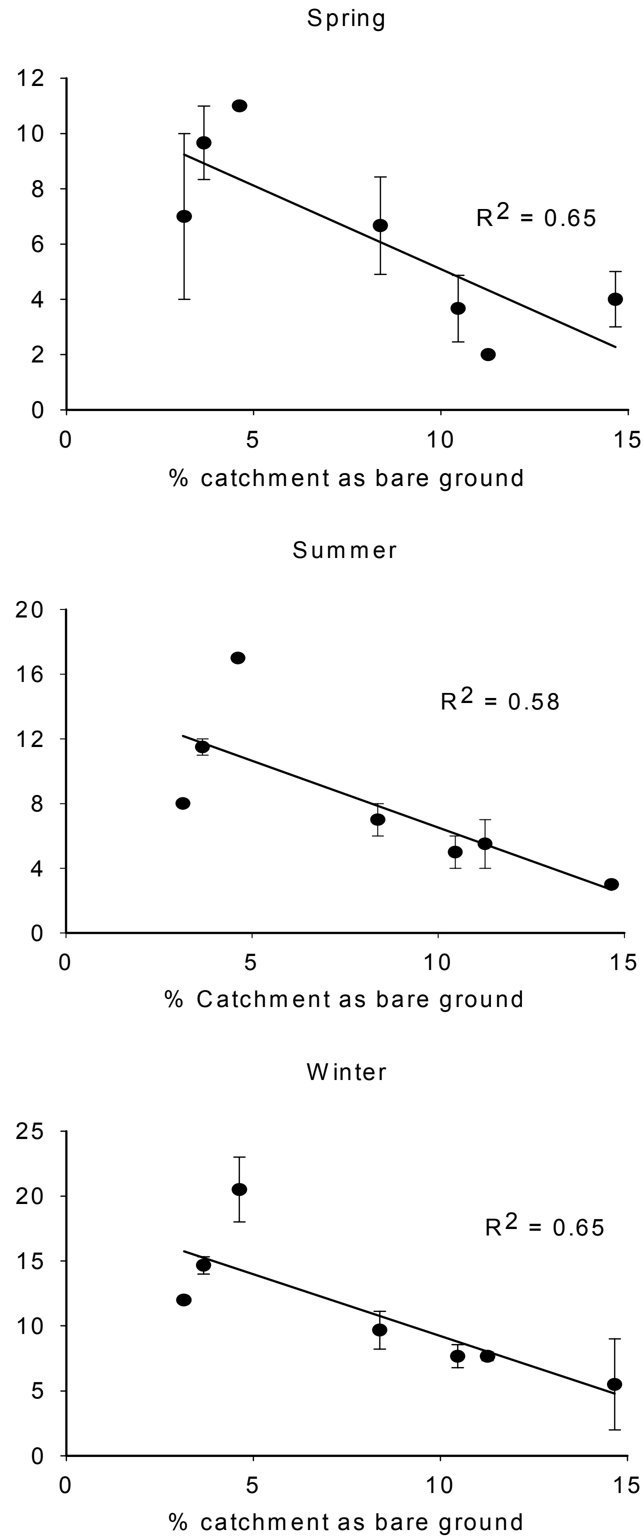


Figure 6-2. Number of macroinvertebrate taxa in the aquatic insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) plotted against % of bare ground in the catchment, for spring, summer and winter, 2000-2002.

Plotted points are individual SEMP streams. All relationships were significant at α = 0.05

During March 2003 and July 2003, we sampled fish assemblages from three run and three pool habitat units from each SEMP stream, using a backpack electroshocker. A total of 10 fish species were found, with the broadstripe shiner (*Pteronotropis euryzonus*), Dixie chubb (*Semotilus thoreauianus*), and the Southern brook lamprey (*Ichthyomyzon gagei*) being the numerically dominant species. Fish species richness was inversely correlated with catchment disturbance intensity (Figure 6-3), suggesting that Fort Benning fish assemblages vary as a function of landscape disturbance.

During 23 and 24 March 2003 we completed our second annual survey of coarse woody debris (CWD) in study streams. Fifteen 1-m wide transects were surveyed in training compartments K13, K20, K11W, D12, D13, and F2/3, and 20 transects were surveyed in training compartment K11E (10 in upper K11E, 10 in lower K11E). CWD serves as habitat for macroinvertebrates and fish, and as such should aid in our understanding of variation in community composition and abundance among streams. CWD abundance remains a good indicator of sediment disturbance, with lower CWD in highly disturbed catchments.

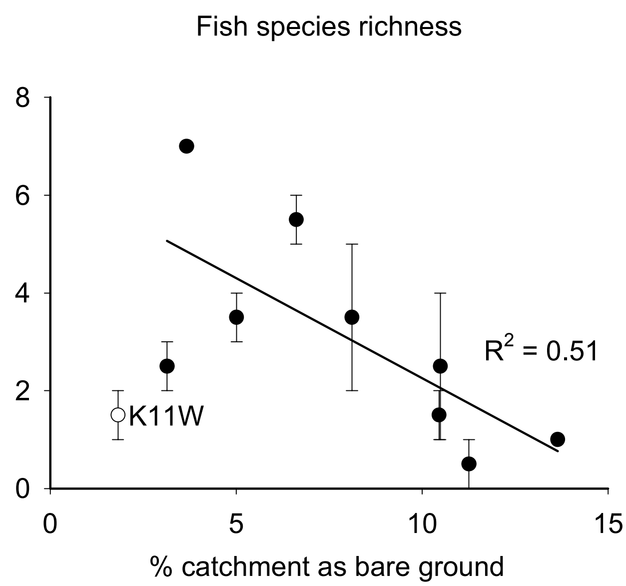


Figure 6-3. Number of fish species plotted against % of bare ground in the catchment. Stream in compartment K11W was considered an outlier because of intermittent flow in Summer 2002. Plotted points are individual SEMP streams, and means of spring and summer 2003 sampling. The relationship was significant at α = 0.05.

6.4 Landscape Indicators - Landscape Analysis

Lisa Olsen and Virginia Dale, Oak Ridge National Laboratory

This research examined landscape indicators that signal ecological change in both intensely used and lightly used lands at Fort Benning. Changes in patterns of land cover through time affect the ecological system. Landscape patterns, therefore, are important indicators of land-use impacts, past and present, upon the landscape. This analysis of landscape pattern began with a landscape characterization based on witness tree data from 1827 and the 1830s and remotely sensed data from 1974, 1983, 1991, and 1999. Witness tree data were collected during land surveys conducted for the U.S. Government in 1827 and the 1830s for the purpose of subdividing and selling land. The Surveyor General surveyed the land, noting the location and species of the corner tree and four witness trees at each corner that marked the boundary of each lot. The data from the early 1800s, although coarse, were useful in characterizing the historical range of variability in ecological conditions for the area. The steps for the analysis involved the creation of a land-cover database and a time series of land-cover maps, computation of landscape metrics, and evaluation of changes in those metrics over time as evidenced in the land-cover maps. An examination of land-cover class and landscape metrics, computed from the maps, indicated that a suite of metrics adequately describes the changing landscape at Fort Benning. The most appropriate metrics were percent cover, total edge (km), number of patches, descriptors of patch area, nearest neighbor distance, the mean perimeter-to-area ratio, clumpiness, and shape range index (which corrects for the size problem of the perimeter-to-area ratio and thus is a measure of overall shape complexity). Identification of such ecological indicators is an important component of building an effective environmental monitoring system.

We are also examining how roads can change the environmental conditions in which they occur by categorizing these effects by spatial scale of the cause and impacts. We are examining the environmental impacts at three spatial scales: a second-order catchment, a third-order watershed, and the entire military installation (in another SERDP project we are considering roads in the five-county area surrounding Fort Benning). The analysis involved different treatments at different scales. Impacts from an experimental tracked vehicle path were examined in the catchment. Land-cover changes based on remote sensing data over the past three decades were considered at the watershed and installation scales. Together these analyses provide a picture of the how environmental impacts of roads and vehicles can occur at different scales. Following tracked vehicle impact with a D7 bulldozer, total vegetation cover responded quickly, but there were differences in recovery between plant species. Soils were compacted in the top 10 cm and are likely to remain so for some time. In examining the watershed from 1974 to 1999, forest conversion was highest near unpaved roads and trails. At the level of the installation, major roads and unpaved roads and tank trails were associated with most of the conversion from forest to nonforest. These results lead to questions about appropriate metrics of road impacts.

6.5 Soil Microbiology

David C. White, Aaron Peacock, and James Cantu
The University of Tennessee Center for Biomarker Analysis

Soil samples were collected from the K-11 experimental site in June and September of 2003 (disturbance experiment). The samples were immediately placed on ice and transported to a laboratory where they were stored in a deep freezer until prepared for analysis. Briefly, the soil was extracted with the single-phase chloroform-methanol-buffer system of Bligh and Dyer. The total lipid extract was fractionated into neutral lipids, glycolipids, and polar lipids by silicic acid column chromotopgraphy.

The fatty acid methyl esters (FAMEs) were analyzed by capillary gas chromatography with flame ionization detection on a Hewlett-Packard 5890 Series 2 chromatograph with a 50-m non-polar column (0.2 mm I.D., 0.11 um film thickness). Preliminary peak identification was performed by comparison of retention times with known standards. Definitive identification of peaks was accomplished by gas chromatography/mass spectroscopy of selected samples using a Hewlett-Packard 6890 series gas chromatograph interfaced to a Hewlett-Packard 5973 mass selective detector using a 20-m non-polar column (0.1 mm I.D., 0.1 μm film thickness).

Data analysis is commencing using both biomass and relative proportions of-phospholipid fatty acids (PLFAs) expressed per gram of soil. Biomass (pmol/g PLFA) and relative proportion (mol%) of specific PLFA will be used to test the null hypothesis that degree of land disturbance will not influence the composition of the soil microbial communities. Additionally data analysis models produced from previous work will be used to test the feasibility of application to the new data.

Soil PLFA data from the previous years (pre and post fire) has been analyzed and will be combined with soil physical and chemical data collected by Chuck Garten and microbial activity data collected by John Dilustro. This combined data set should provide information regarding soil microbial community changes along transects from upland to wetland areas. What is unique about this data relative to the previous work is the addition of the activity and soil parameters heretofore not measured. The inclusive data set provides information about the microbial community structure and biomass and connects the information with microbial respiration and soil habitat.

6.6 Project Products

Publications

- Journal (published or in press): 6
- Book chapters or symposium proceedings: 1
- Other: 2
- Journal (In preparation): 9

Presentations

- Professional meetings: 29
- Other meetings: 8

Data entered into the SEMP ECMI Data Repository

- Metadata for two historical data sets
- Historical witness tree data
- Historical land cover GIS coverage.
- Vegetation data from plots
- Baseflow water chemistry data for each site
- Stream marcoinvertebrate data
- Soil microbial PLFA data

6.6.1 Products of SERDP Ecological Indicators Project

Papers in preparation

Cantu J. M., A.D. Peacock, V.H. Dale, A.N. Smithgall, D.C. White. Community Structure and Physiological Status of Subsurface Microbial Communities Based on Surface Disturbance. Journal of Microbial Ecology.
Significance: The impact of soil disturbance on soil microbes.
To submit: May 2004

Dale, V.H., Peacock, A., C. Garten, and A. Wolfe. Contributions of soil, microbial, and plant indicators to land management of Georgia pine forests. Ecological Applications.
Significance: A comparison of indicators of soil, plant and microbial condition.
To submit: May 2004

Dale,V.H, Duckenbrod, D., Baskaran, L., Aldridge, M.., Berry, M., Garten, C., Olsen, L., Efroymson, R., and Washington-Allen, R. In preparation. Vehicle impacts on the environment at different spatial scales: Observations in west central Georgia. Journal of Terramechanics.
Significance: A comparison of vehicle and road impacts at different scales.
To submit: January 2004

Dale, VH., Olsen, L.M. and H.T. Foster. Landscape patterns as indicators of ecological change at Fort Benning, GA. Land Use and Urban Planning
Significance: Documents procedures and use of landscape indicators at Fort Benning
Submitted: December 2003

Maloney, K.O., P.J. Mulholland, and J.W. Feminella. The effects of catchment-scale land use patterns on physicochemistry in small Southeastern Plains streams. Journal of the North American Benthological Society.
Significance: This paper reports on the effects of catchment land use from military activities on stream physicochemical variables (e. g. water chemistry, habitat, stability). The significance of this paper is that it reports on catchment scale disturbance void of urban and contemporary agricultural practices. The majority of past studies could not separate these land use effects.
To Submit: April 2004

Maloney, K.O., J.W. Feminella, P.L. Chaney, and A. Abebe. Assessing the effects of catchment land use on streambed stability: A comparison of three stability methods. Earth, Surface Processes, and Landforms OR Journal of the American Water Resources Association.
Significance: This paper compares ability of three measures of streambed stability to indicate catchment land use patterns. Streambed stability is an important stream habitat feature which has been shown to negatively affect the macroinvertebrate and fish communities. The significance of this paper is that it compares the effects of sampling length and season on each method, which has not been reported to date.
To Submit: April 2004.

Maloney, K.O. and J.W. Feminella. The relationship between catchment-scale military land use with stream macroinvertebrate and fish assemblages. Journal of the North American Benthological Society.
Significance: This manuscript reports on the effects of military land use on the macroinvertebrate and fish assemblages in small (second to third order) streams on the Fort Benning Military Installation. The significant aspects of this paper are that 1) it reports on small sandy-bottomed streams which have received limited ecological study, and 2) reports on catchment-scale disturbance without urban or contemporary agricultural practices, which are often difficult to discriminate between.
To Submit: May 2004

Mulholland, P.J. , J. N. Houser, and K. Maloney. Stream chemistry indicators of disturbance on military reservations. Ecological Indicators.
Significance: Stream chemistry parameters may be useful indicators of ecosystem disturbances at the watershed scale. We evaluated a number of potential stream chemistry parameters as indicators of disturbance, including sediment and nutrient concentrations and diurnal dissolved oxygen profiles. These parameters were evaluated both under baseflow and stormflow conditions and during different seasons.
To submit: May 2004

Wolfe, A., and Dale, V.H., and Peacock, A. Ecological research for natural resource management: Integrating the science and aligning research with practice. Journal of Environmental Management.
Significance: How scientists can better communicate with resource managers.
To submit: April 2004

Posters

Dale, V.H. and Beyeler, S.C. Ecological indicators: Tools for ecosystem management. SERDP Symposium, Dec. 1999, Washington, DC.

Dale, V.H. Ecological indicators. Workshop on Ecological Models for Resource Management. Oct. 2000, Oak Ridge TN.

Dale, V.H., Feminella, J., Foster, T., Mulholland, P., Olsen, L., Peacock, A., White, D. "Ecological indicators for land management. Ecological Society of America Annual Meeting, Aug. 2001, Madison, WI.

Dale, V.H., Feminella, J., Foster, T., Mulholland, P., Olsen, L. Selecting a suite of ecological indicators for land management. SERDP Symposium, Dec. 2001, Washington, DC.

Maloney, K.O., J.W. Feminella, and P.J. Mulholland. Effects of watershed disturbance on macroinvertebrate communities in small streams at Fort Benning, GA. 2002 North American Benthological Society, Pittsburgh, PA.

Dale, V.H., Feminella, J., Maloney, K., Mulholland, P., Olsen, L, Peacock, A., and White, D. Tools for resource management. SERDP Symposium, Dec. 2002, Washington, DC.

Presentations (in addition to the many presentations made at internal SEMP meetings)

Dale, V.H. Views from the Ridge: Considerations for Planning at the Landscape Scale, sponsored by the Pacific Northwest Research Station, USDA Forest Service, Vancouver, Washington, Nov. 2-4, 1999.

Dale, V. H. Symposium on “Urban landscape ecology” at the 15th Annual US Landscape Ecology Symposium, Fort Lauderdale, Fl., April 15-19, 2000.

Dale. V.H. EcoSummit 2000: Integrating the Science. Halifax, Nova Scotia, Canada, June 18-22, 2000.

Dale, V.H. Using indicators for restoration and management. Ohio State University. November 2, 2000.

Dale, V.H. Lessons for Ecosystem Management. Fall Line Workshop. March 6-7, 2001, Aiken, S.C.

Dale, V.H. Use of indicators. Workshop on “Climate Change and Species Survival: Implications for Conservation Strategies,” February 19-21, 2001, The World Conservation Union (IUCN) in Gland, Switzerland.

Dale, V.H. “Top Ten Issues in Landscape Ecology” session at the 16th Annual Symposium on Landscape Ecology, Tempe Arizona, April 2001

Dale, V.H. Virginia Polytechnic Institute, Blacksburg, Virginia, April 2001

Dale, V.H. University of Illinois in Chicago, April 2001

Dale, V.H. SERDP SAB, Washington, DC, June 2001

Dale, V.H. SEMP Technical Advisory Committee, Washington, DC, July 2001

Dale, V.H. Workshop on "Community-based Stewardship of Natural Lands" held at the Ecological Society of America Annual Meeting, Madison, WI, August 6, 2001.

Dale, V.H. SEMP Research Coordination Meeting, Columbus, GA, Nov. 2001

Dale, V.H. SEMP Technical Advisory Committee, Washington, DC, April 2002.

Dale, V.H. SEMP Technical Advisory Committee, Columbus, GA October, April 2002.

Dale, V.H. Pardee Symposium on "Geologic and Ecologic Responses to Landscape Disturbances" at the Geological Society of America, October 29, 2002 in Denver, Colorado.

Dale, V.H. Botany Department, University of Tennessee, November 2002.

Dale, V., L.Olsen, and T. Foster. Landscape Patterns as Indicators of Ecological Change at Fort Benning, GA. US International Association for Landscape Ecology 17th annual symposium in Lincoln, Nebraska, April 2002.

Foster, T. "Evolutionary Ecology of Creek Residential Mobility," Southeastern Archaeological Conference, Macon, Georgia, November 2000.

Foster, T. " Witness tree analysis of Native American influences on the distribution of forest trees An example among the Creek Indians of the Southeastern U.S. Society of American Archaeology, Denver, CO, March 20, 2002.

Maloney, K.O., J.W. Feminella, P.J. Mulholland, V. H. Dale and L. M. Olsen. Effects of past and present land use practices on small streams at Fort Benning, Georgia. Ecological Society of America. Tucson, AR, August 2002.

Maloney, K. O., J. W. Feminella, and P. J. Mulholland. Effects of watershed disturbance on macroinvertebrate communities in small streams at Fort Benning, GA. North American Benthological Society, May 29-June 1, 2002, Pittsburg, PA.

Mulholland, P. J., J. N. Houser, J. W. Feminella, and K. O. Maloney. Stream indicators of ecological impacts from military training at Fort Benning, GA. Ecological Society of America, Aug. 4-8, 2002, Tucson, AZ.

Olsen, Lisa M., Virginia Dale, and Thomas Foster. Landscape Patterns as Indicators of Ecological Change at Fort Benning, GA. ESRI User Conference, July 9-13, 2001, San Diego, CA.

White, D.C., Peacock, A.D., S. J. Macnaughton, J. M. Cantu, V. H. Dale. Ninth International Symposium on Microbial Ecology Interactions in the Microbial World, Amsterdam, The Netherlands. "Changes in soil viable microbial biomass and composition reflect disturbance impacts and may serve as quantitative end points for reversibility" (Mo.O59); August 27, 2001.

6.6.2 Indirect products of SERDP project

Books

Dale, V.H. and Haeuber, R.A. (editors). 2001. Applying Ecological Principles to Land Management. Springer-Verlag: New York.

Dale, V.H. (editor) 2003. Ecological Modeling for Resource Management. New York: Springer-Verlag.

Forman, RT.,D. Sperling, J. Bissonette, A. Clevenger, C. Cutshall, V.H. Dale, L. Fahrig, R. France, C. Goldman, K. Heanue, J. Jones, F. Swanson, T. Turrentine, and T. Winter. 2002. Road Ecology: Science and Solutions. Island Press.

Chapters

Dale,V.H.,S. Brown, R. A. Haeuber, N. T. Hobbs, N. Huntly, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone. 2001. Ecological Guidelines for Land Use and Management. Pages 3-36 In (V. H. Dale and R. A. Haeuber, editors). Applying Ecological Principles to Land Management. Springer Verlag: New York.

Dale, V.H. 2001. Applying Ecological Guidelines for Land Management to Farming in the Brazilian Amazon. Pages 213-215 In (V. H. Dale and R. A. Haeuber, editors). Applying Ecological Principles to Land Management. Springer Verlag: New York.

Dale, V. 2003. New directions in ecological modeling for resource management. In Dale, V.H. (editor) Ecological Modeling for Resource Management. New York: Springer-Verlag.

Dale, V. 2003. The value of ecological modeling for resource management. In Dale, V.H. (editor) Ecological Modeling for Resource Management. New York: Springer-Verlag.

Dale, V. H., Fortes, D. T., and Ashwood, T. L. 2002. A landscape transition matrix approach for land management. Pages 265-293 In (J. Liu and W. Taylor, ed.) Integrating Landscape Ecology into Natural Resource Management. Cambridge University Press.

Dale, V., C. Rewerts, W. Van Winkle, M. Harwell, M. Vasiesich, and S. Hodapp 2003. Barriers to the use of ecological models in decision making. In Dale, V.H. (editor) Ecological Modeling for Resource Management. New York: Springer-Verlag.

Haeuber, R. and Dale V.H. 2001. New directions in land management: Incorporation of ecological principles. In (V. H. Dale and R. A. Haeuber, editors), Applying Ecological Principles to Land Management. Springer-Verlag: New York..

Gustafson, E., J. Nestler, L. Gross, K. Reynolds, D. Yaussy, T. Maxwell, and V. Dale. 2003. Evolving approaches and technologies to enhance the role of ecological modeling in decision making. In Dale, V.H. (editor) Ecological Modeling for Resource Management. New York: Springer-Verlag.

Hohler, D., T. Ashwood, J. Richardson, L. Olsen, N. Hendrix, and A. Williams. 2003. Effective ecological modeling for use in management decisions: Data Issues. In Dale, V.H. (editor) Ecological Modeling for Resource Management. New York: Springer-Verlag.

King, W.C. and V. Dale. 2003. What in the World Is worth fighting for? Using models for environmental security, In Dale, V.H. (editor) Ecological Modeling for Resource Management. New York: Springer-Verlag.

Noon, B.R. and V.H. Dale. 2002. Broad scale ecological science and its applications. Pages 34-52 In (K. Gutzwiller, ed.) Applying Landscape Ecology in Biological Conservation. New York: Springer-Verlag.

Papers

Russell, C., Dale, V., Lee, J., Jensen, M.H., Kane, M., Gregory, R. 2001. Experimenting with multi-attribute utility survey methods in a multidimensional valuation problem. Ecological Economics 36: 87-108.

Schiller, A., C. T. Hunsaker, M. A. Kane, A. K. Wolfe, V. H. Dale, G. W. Suter, C.S. Russell, G. Pion, M. Hadley, and V. C. Konar. In press. Communicating ecological indicators to decision-makers and the public. Conservation Ecology.

Harwell, M.A., W. Adams, S.M. Bartell, K.W. Cummins, V. Dale, C. Johnston, F.K. Pfaender, W.H. Smith, T.P. Young, and S. Sanzone. In review. Assessing relative risks to ecological systems. Environmental Management.

Report

U.S. EPA. 2002. An Science Advisory Board Report: A Framework for Assessing and Reporting on Ecological Condition. Report EPA-SAB-EPEC.

7 Disturbance of Soil Organic Matter and Nitrogen Dynamics: Implications for Soil and Water Quality – 1114D

Annual Report

October 1, 2002 - September 30, 2003 (FY03)

Charles T. Garten, Jr., and Robert Washington-Allen

Environmental Sciences Division, Oak Ridge National Laboratory

7.1 Accomplishments Summary

ORNL Team 2 had accomplishments during FY03 in the areas of:

1. meetings, presentations, and publications,
2. field sampling, data analysis, and interpretation, and
3. model research and development for the purpose of predicting thresholds in soil quality to ecosystem recovery and sustainability at Fort Benning, Georgia.

7.1.1 Meetings, Presentations, and Publications

During FY03, ORNL Team 2 delivered two presentations to advisory committees, presented a poster at the SERDP Partners in Environmental Technology Symposium in Washington, DC, revised two manuscripts for peer-reviewed journals, prepared a proposed expansion of research scope at the request of the SEMP Technical Advisory Committee, published a peer-reviewed article in the journal *Ecological Indicators*, participated in the SEMP Research Integration Meeting in Gainesville, FL, and prepared a research close-out plan. In addition, required SEMP quarterly reports, an FY02 annual report, an FY02 executive summary, and an FY03 research execution plan were completed and submitted on-time to the SEMP program office.

7.1.2 Field Sampling, Data Analysis, and Interpretation

During FY03, ORNL Team 2 completed post-disturbance soil sampling at the K-11 experimental site on Fort Benning, completed a summary of data for all soil samples collected by ORNL Team 2 at Fort Benning, submitted metadata and data files to the SEMP Data Repository for soil samples collected at Fort Benning prior to December 2002, prepared photographs of 129 sampling sites at Fort Benning for transmittal to the SEMP Data Repository, and provided assistance to the Savannah River Ecology Laboratory (SREL) researchers by analyzing their soil samples for carbon and nitrogen. The preparation and laboratory analysis of post-disturbance soil samples collected at the K-11 experimental area was continued into FY04.

7.1.3 Model Research and Development

During FY03, ORNL Team 2 revised a spreadsheet model for predicting thresholds of soil quality to ecosystem recovery at Fort Benning to account for differences in soil type, and continued to refine a Stella® multi-compartment model to predict the dynamics of plant biomass and soil quality under different management scenarios. The model has been used as part of an analysis of recovery potential and sustainability of forest ecosystems under different regimes of forest harvesting and prescribed burning. Progress was also made toward the development of a GIS-based model for predicting potential excess nitrogen at the landscape scale on Fort Benning.

7.2 Background

The deterioration of soil quality can lead to dramatic and long-term changes in terrestrial ecosystems, but little is currently known about what thresholds may exist that prolong or prohibit the recovery of soil quality following ecosystem disturbance. The mission of this project, within the framework of the SERDP Ecosystem Management Project (SEMP), is to evaluate the short- and long-term effects of land use change and terrestrial ecosystem disturbance on two key measures of soil quality: soil organic matter (i.e., soil carbon) and soil nitrogen dynamics.

ORNL Team 2 is conducting studies of soil carbon and nitrogen dynamics across a range of spatial scales at Fort Benning, Gorogia. The most intensive studies are being performed in the K-11 training compartment in association with an experiment on the effects of heavy vehicle disturbances. Broader scale studies, at the installation level across both upland and lowland terrain, involve sampling sites that have been distributed to varying degrees by military activities.[1]

The latter studies, which have been summarized in prior reports, are focused on the effects of military and forestry disturbances on key measures of soil quality as well as the potential recovery of soil quality following site disturbance. Our science questions are:

1. Can soil carbon and nitrogen dynamics be used to identify nutrient resource thresholds to recovery of desired future ecosystem conditions at Fort Benning?
2. How do disturbances associated with military activity and forestry affect measures of soil quality?
3. Which soil attributes and processes are good candidates for indicators of ecosystem disturbance and the identification of thresholds to recovery or sustainability?

7.3 Objectives

Ecosystem recovery and sustainability are important elements of conservation efforts on military lands. Carbon and nitrogen are important determinants of soil quality, which ultimately affects the recovery and sustainability of terrestrial ecosystems following ecosystem disturbance. The objectives of this research are to develop models of soil carbon and nitrogen dynamics, to predict soil quality thresholds to ecosystem recovery, and to evaluate the potential for recovery and sustainability of soil quality associated with different types of disturbance and land management practices.

The objectives of the study are being accomplished through the following research tasks that were set forth in the original proposal:

1. Characterize the effect of disturbances and land cover on key measures of soil quality (i.e., describe how soil carbon and nitrogen dynamics are affected by current DoD land use activities and natural disturbance regimes).
2. Determine whether there are thresholds associated with natural and/or anthropogenic disturbance that establish the potential recovery of soil quality following site disturbance (i.e., describe how current DoD activities and/or land use activi-

[1] Garten, C.T., Jr., T.L. Ashwood, and V.H. Dale. 2003. Effect of military training on indicators of soil quality at Fort Benning, Georgia. Ecological Indicators 3: 171-179.

ties affect the potential for short- to long-term recovery of soil quality in disturbed environments).

3. Build simple dynamic models of soil carbon and nitrogen for different land cover categories to predict the recovery of soil quality on disturbed lands.
4. Conduct long-term field experiments to calibrate and test models used to predict the recovery of soil quality (including soil carbon sequestration) following disturbance caused by DoD activities.
5. Use existing GIS resources as a tool for analysis of spatial patterns of soil carbon and nitrogen and as a basis for predicting the effect of site disturbance and/or land cover change on soil quality and nonpoint sources of nitrogen to surface water drainages.

7.4 Approach

The approach to the research involves a combination of field studies and systems modeling. Field measurements from disturbance gradients, different land cover categories, and forest chronosequence sites have been used to build mathematical models for predicting system response to disturbance and identifying thresholds to recovery following ecosystem disturbance. The models and the field data will also be used in combination with GIS data for a landscape-level analysis of soil carbon and nitrogen stocks.

Field measurements of soil density, soil carbon, and soil nitrogen dynamics have been made in ecosystems along gradients of disturbance and under different land cover types (e.g., forests, old-fields, disturbed, and undisturbed lands) at Fort Benning, Georgia. Soil samples are usually collected to a depth of 40 cm and are divided into surface litter (O-horizon) and mineral soil. The mineral soil is further subdivided into 10-cm increments. The various portions are analyzed for total carbon and nitrogen concentrations. Soil nitrogen availability is determined by measuring potential net soil nitrogen mineralization under laboratory conditions. Soil carbon inventories are further partitioned into labile, organo-mineral, and refractory pools using laboratory techniques.

Soil samples have been collected along disturbance gradients, under different land covers, along forest chronosequences, and at forest sites used for disturbance experiments. Information and data from the field studies has been incorporated into mathematical models of soil carbon and nitrogen dynamics. These models allow prediction of the recovery of soil quality at Fort Benning following site disturbance. The models also allow us to explore disturbance thresholds that possibly impact the potential for short- and long-term recovery of soil quality following site disturbance. We have also measured soil carbon and nitrogen stocks under different land cover types for the purpose of mapping key measures of soil quality using a geographic information system.

7.5 Progress Summary for Field Research (FY03)

7.5.1 Field Studies at K-11 Experimental Site

During this report period, ORNL Team 2 completed post-disturbance soil sampling at the experiment in the K-11 training compartment. Soil sampling was conducted in mid-June and coordinated with plant sampling by ORNL Team 1 (see SEMP Ecological Indicators – 1114C, page 113). ORNL Team 2 collected paired soil cores (to a 30-cm soil depth) at seven disturbed locations and seven control points. Samples were also collected for analysis of potential net soil nitrogen mineralization inside and outside the areas of soil disturbance. John Dilustro from the Savannah River Ecological Laboratory (SREL, see Thresholds of Disturbance: Land Management Effects on Vegetation and Nitrogen Dynamics – 1114E, page 140) placed sampling points for soil respiration at some of the same locations where ORNL Team 2 collected soil samples.

Mass of the O-horizon was significantly reduced at K-11 along the treatment transect (257 g m^{-2}) compared to the control transect (640 g m^{-2}) ($P < 0.01$). Thus, the treatment caused a substantial reduction in forest floor organic matter. Surface (0-10 cm) soil density under the treatment transect was significantly greater than that under the control transect ($P < 0.05$). The mean (±SE) densities of surface soil samples from the treatment and control transects were 1.43 ±0.03 and 1.28 ±0.06, respectively. Although soil densities for increments deeper than 10 cm tended to be greater under the treatment transect, the differences were not significantly different from the controls. Soil compaction from heavy vehicle traffic at K-11 was primarily limited to the surface mineral soil layer and produced an increase of approximately 12% in surface soil density.

The post-disturbance soil samples are currently being prepared for analysis of total soil carbon and nitrogen concentrations and stocks, carbon and nitrogen in particulate organic matter and mineral-associated organic matter, and soil nitrogen availability. The soil cores (n = 28) were cut into 10-cm increments, air-dried, and weighed. The soil samples will be crushed, sieved, and prepared for elemental analysis in early FY04. Post-disturbance soil cores from K-11 were also prepared for laboratory incubations to determine differences in potential net soil nitrogen mineralization between disturbed and control sites. We will test for differences in measures of soil quality between disturbed soils and their controls using analysis of variance. Data collected in the post-disturbance environment will also be compared with data from pre-disturbance soil sampling conducted in previous years at the same location.

7.5.2 Field Data Summarization

In FY03, ORNL Team 2 completed a summarization of measures of soil quality for over 100 sites under perennial vegetation and at 20 sites where there has been recent soil disturbance at Fort Benning. Simple descriptive statistics have been used to summarize measures of soil quality (e.g., soil carbon and nitrogen levels and soil nitrogen availability) and the following comparisons were completed:

1. Comparisons of clear-cut and control forest soils at various times (1, 6, or 11 years) after clear-cutting.
2. Comparisons of riparian and upland sampling sites in the K-11 training compartment in April and October 2001.
3. Comparisons along a chronosequence of longleaf pine stands (10, 12, 56, 70, 75, and 82 year old stands).
4. Comparisons of different land cover categories (e.g., barren sites, old-fields, pine forests, and deciduous forests).
5. Comparisons of young (n = 11) and mature (n = 16) pine stands.
6. Comparisons of old field and forest sites on soils with differing sand content.

One of the interesting patterns to emerge from these comparisons is the influence of sand content on measures of soil quality. Sand content in 129 soil samples collected at Fort Benning ranged from 12% to 95%. The mean sand content was 70% and two-thirds of the samples collected had a sand content that exceeded the mean. For the purpose of comparisons, each soil sample was binned into one of two categories (i.e., “less sandy” or “more sandy”) based on whether the sand content was less than or more than 70%. Old field and forest sites on less sandy soils have significantly greater soil carbon and nitrogen stocks than those on more sandy soils.

The mean potential net soil nitrogen mineralization rate, expressed on an annual basis, was greater for soils with more than 70% sand content. More sandy soils under perennial vegetation had a significantly ($P < 0.001$) greater fraction of soil carbon in particulate organic matter (POM) and significantly ($P < 0.05$) greater stocks of surface mineral soil POM carbon than less sandy soils. Particulate organic matter is a highly labile carbon pool that may be important to nitrogen retention and availability in some soils. Higher potential net soil nitrogen mineralization rates in more sandy soils at Fort Benning are attributed to the greater amounts of labile soil organic matter.

During FY03, metadata and data files for soils collected at Fort Benning through 2002 by ORNL Team 2 were transmitted to the SEMP Data Repository. The data file contained 114 variables from 129 study sites (20 barren sites and 109 sites under perennial vegetation). Digital photographs of the study sites were organized and a metadata file was prepared that describes the image data set. These data files are currently being used in the SEMP Research Integration effort.

7.6 Progress Summary for Modeling (FY03)

7.6.1 Threshold Model Research and Development

The objective of the first modeling task is to use simple models of soil carbon and nitrogen dynamics to predict nutrient thresholds to ecosystem recovery on degraded soils at Fort Benning. The model calculates aboveground and belowground biomass, soil carbon inputs and dynamics, soil nitrogen stocks and availability, and plant nitrogen requirements. A threshold is crossed when predicted soil nitrogen supplies fall short of predicted nitrogen required to sustain biomass accrual at a specified recovery rate.

Four factors were found to be important to development of thresholds to recovery: (1) initial amounts of aboveground biomass, (2) initial soil carbon stocks (i.e., soil quality), (3) relative recovery rates of biomass, and (4) soil sand content. Thresholds to ecosystem recovery predicted by the model should not be interpreted independent of a specified recovery rate. Initial soil carbon stocks influenced the predicted patterns of recovery by both old field and forest ecosystems. Forests and old fields on soils with varying sand content had different predicted thresholds to recovery.

Soil carbon stocks at barren sites on Fort Benning generally were less than the predicted thresholds for 100% recovery of desired future ecosystem conditions defined on the basis of aboveground biomass (18000 versus 360 g m^{-2} for forests and old fields, respectively). Calculations with the model indicated that reestablishment of vegetation on barren sites to a level below the desired future condition is possible at recovery rates used in the model, but the time to 100% recovery of desired future conditions, without crossing a nutrient threshold, is prolonged by a reduced rate of forest growth. Predicted thresholds to ecosystem recovery were less on soils with more than 70% sand content. The lower thresholds for old field and forest recovery on more sandy soils are apparently due to higher relative rates of net soil nitrogen mineralization in more sandy soils. Calculations with the model indicate that a combination of desired future conditions, initial levels of soil quality (defined by soil carbon stocks), and the rate of biomass accumulation determines the predicted success of ecosystem recovery on disturbed soils.

During FY03, ORNL Team 2 also revised a multi-compartment model of soil carbon and nitrogen dynamics, developed with Stella® modeling software. The model has been used to simulate various land management practices at Fort Benning. These practices/scenarios include maintenance of forest cover, forest recovery on barren soils, and forestry with a variable interval of prescribed burning. Mean (±SE) measured soil carbon stocks at 8 barren sites on Fort Benning were 700 (±240) g C m^{-2}. This amount of soil carbon was used as an initial condition for predicting recovery to desired future ecosystem conditions defined on the basis of aboveground biomass (18,000 and 360 g dry mass m^{-2} for forests and old fields, respectively). With no limiting factors, forest biomass achieved steady state in approximately 50 years.

Model simulations indicated that prescribed burning with less than a 5-year return interval reduced predicted soil carbon and nitrogen stocks (soil carbon under a 1-yr cycle was 66% of that under a 3-yr cycle and 58% of that under a 5-yr cycle). At sites with low soil nitrogen availability (i.e., less sandy soils), the model predicts more frequent burning promotes forest recovery on barren soils by stimulating nitrogen fixation. If annual N-fixation is small (<5 g m^{-2}), a 3-year return interval for prescribed fires reduces the predicted rate of forest recovery on barren soils. Sensitivity analysis indicated the following parameters are important to model predictions: soil carbon turnover times, root turnover, maximum N-fixation, within-tree nitrogen translocation, net soil nitrogen mineralization, and tissue nitrogen concentrations. In the absence of prescribed burning, there is no apparent N-fixation threshold to ecosystem recovery at sites with either low or high soil nitrogen availability. With a 3-year burn interval, a threshold in N-fixation to forest recovery is apparent on both less sandy and more sandy soils. Experimentation with the model revealed that interactions between fire, N-fixation, and soil nitrogen availability can give rise to complex predicted patterns of ecosystem recovery.

7.6.2 Spatial Modeling of Potential Excess Nitrogen

The objective of the second modeling task is to derive annual and seasonal estimates of potential excess nitrogen (PEN) on Fort Benning. A general, mass balance approach in a spatial modeling context originally developed for the Neuse River Basin in North Carolina was used to calculate PEN, which is the difference between nitrogen inputs (atmospheric deposition, fertilization, and soil nitrogen mineralization) and nitrogen outputs (plant uptake, volatilization, and denitrification) at the landscape scale. Atmospheric nitrogen deposition was obtained from monitoring stations that are part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) surrounding Fort Benning. Other nitrogen cycling processes have been estimated on the basis of land cover using a 1998 land-cover map from the University of Georgia in combination with field and literature data. In one version of the model, field data from Fort Benning were used to estimate the net soil nitrogen mineralization flux. In a second version of the model, net soil nitrogen mineralization was calculated using a soil nitrogen inventory map that was derived from U.S. Department of Agriculture/ Natural Resources Conservation Service National Soil Characterization Database and the State Soil Geographic (STATSGO) database. In both versions, map algebra was used to generate annual and seasonal maps of PEN. The PEN maps were compared and the difference map suggested that the soil nitrogen map approach provides results that are consistent with the surface steam network.

We are in the process of estimating PEN loading to streams on Fort Benning by using an empirical, nutrient transport, hydrological model. This approach initially assumes overland flow, but the model then uses the concept of vegetated filter-strips as traps for nutrients to estimate delivery ratios for nitrogen. This model requires spatial data on surface roughness [mean particle diameter and Manning's roughness coefficient (n)], slope angle, and distance of flow to calculate the delivery ratio. Mean particle diameter has been derived from STATSGO soil texture data and estimates of mean particle diameter based on soils data from Fort Benning. The appropriate n value was assigned to each land cover type in the 1998 land cover map. The result will be an estimate of the trapping efficiency of the land surface. One minus the trapping efficiency is equal to the delivery ratio. The delivery ratio is then related to flow path and the accumulation data that is derived from a digital elevation model. The end products are spatial maps that show the calculation of total seasonal and annual loads of nitrogen to surface receiving waters at Fort Benning. We plan to complete this modeling task for Fort Benning in FY04.

7.7 Project Close-out

The project has a scheduled completion date of February 2004. The following tasks have been identified as the project close-out plan:

- Progress report to TAC - Oct. 2003 (completed)
- Submit photos of 129 study sites to SEMP Data Repository

- Complete experimentation and testing of Stella Model - Nov. 2003 (completed)
- Present poster at Partners in Environmental Technology Symposium (SERDP/ESTCP) - Dec. 2003 (completed)
- Annual report for 2003 (completed)
- Complete preliminary spatial analysis of soil C, N, and PEN - Jan. 2003
- Final report to TAC - Spring 2004
- Continue working on manuscripts (1 submitted and 5 in preparation)

7.8 Milestones

Milestones for FY03 and their current status are summarized below.

1. Nitrogen mineralization study in collaboration with CS-1114E (SREL, Collins); scheduled Completion Date: Mar. 2004. The purpose of this task is to summarize data on potential net soil nitrogen mineralization rates from different land cover types at Fort Benning. SREL and ORNL Team 2 are using the same method for laboratory determinations of soil nitrogen availability at their respective study sites. As a point of collaboration, SREL and ORNL Team 2 decided to compare and compile their respective data sets in order to broaden our understanding of factors controlling soil nitrogen availability across the installation.
2. Complete an analysis of soil carbon and nitrogen (including soil nitrogen dynamics) for all soil samples taken at Fort Benning prior to Dec. 31, 2002; scheduled Completion Date: June 2003. The milestone was completed.
3. Submit data on soil carbon and nitrogen concentrations and stocks and net soil nitrogen mineralization potential to the SEMP Data Repository on the ECMI web site for all ORNL Team 2 study sites; scheduled Completion Date: Sep. 2003. The milestone has been completed.
4. Evaluate and interpret the importance of different land cover categories as non-point sources of nitrogen to surface receiving waters (i.e., complete calculations of potential excess nitrogen under different land cover categories); scheduled Completion Date: Sep. 2003. The milestone was completed.
5. Revise two manuscripts presently submitted for publication and resubmit to technical journals for publication; scheduled Completion Date: Sep. 2003. The milestone was completed.
6. Participate in research integration effort; scheduled Completion Date: Continuous. The milestone is ongoing.

7.9 Products

During FY03, ORNL Team 2 completed the following presentations and papers:

Garten, C.T., Jr., and T.L. Ashwood, “Disturbance of soil organic matter and nitrogen dynamics: implications for soil and water quality”, Platform presentation at SERDP Scientific Advisory Board Meeting, Oct. 2002, Washington, DC.

Garten, C.T., Jr., and T.L. Ashwood, “Disturbance of soil organic matter and nitrogen dynamics: implications for soil and water quality”, Platform presentation at SEMP Research Coordination Meeting, Oct. 2002, Columbus, GA.

Garten, C.T., Jr., and T.L. Ashwood, “Resource threshold modelling based on soil carbon and nitrogen dynamics at Fort Benning, GA”, Poster presentation at 2002 Partners in Environmental Technology Technical Symposium and Workshop, Dec. 2002, Washington, DC.

Garten, C.T., Jr., T.L. Ashwood, and V.H. Dale. 2003. Effect of military training on indicators of soil quality at Fort Benning, Georgia. Ecological Indicators 3: 171-179.

Garten, C.T., Jr., and T.L. Ashwood. 2003. Land cover differences in soil carbon and nitrogen at Fort Benning, Georgia. Applied Soil Ecology (submitted June 2003).

Dale, V.H., D. Druckenbrod, L. Baskaran, M. Aldridge, M. Berry, C. Garten, L. Olsen, R. Efroymson, and R. Washington-Allen. 2003. Vehicle impacts on the environment at different spatial scales: observations in west central Georgia. Journal of Terramechanics (submitted November 2003).

Garten, C.T., Jr. 2003. Modeling soil quality thresholds to ecosystem recovery at Fort Benning, Georgia, USA. Journal of Applied Ecology (completed and awaiting submission).

8 Thresholds of Disturbance: Land Management Effects on Vegetation and Nitrogen Dynamics – 1114E

Annual Progress Report
October 1, 2002 - September 30, 2003 (FY03)
Savannah River Ecology Laboratory
Beverly S. Collins
Dr. John Dilustro
Dr. Rebecca Sharitz
Dr. Christopher Romanek
Dr. J Vaun McArthur

8.1 Introduction

8.1.1 Background

Land at Fort Benning must sustain the military training mission. Current land use for training involves lighter disturbance by foot and light vehicle traffic through heavier disturbance by repeated heavy vehicle traffic. A second land management goal is sustainable upland forests. These mixed-pine-hardwood forests are on ridgetops and upper slopes on sandy and clayey soils. They are managed through thinning and prescribed burning to promote longleaf pine (*Pinus palustris*) forest, which provides economic benefits and supports the endangered red-cockaded woodpecker (*Picoides borealis*).

Some combinations of military and forestry land use may not be sustainable. The forest cannot recover or continue its desired trajectory; it may lose nutrients or fail to regenerate key species. Land managers at Fort Benning need information to determine what combinations of military training and forest management exceed thresholds beyond which upland ecosystems are not sustainable.

8.1.2 Objective

The broad objective of our research is to evaluate the ecological effects of military training and forest management at Fort Benning, to determine if there are thresholds beyond which upland mixed-pine-oak forests cannot sustain the combined effects of thinning, burning, and military training disturbances.

8.1.3 Approach

We are taking an experimental approach to test the hypothesis that underlying soil type partly determines nutrient cycling, species diversity, and vegetation dynamics on a site, and influences thresholds for sustainable land use. We are comparing cycling of a key element, nitrogen, as well as species diversity and vegetation dynamics of sites on clayey and sandy soils subjected to different forest management scenarios (burned on 2-yr cycle, burned on 4-yr cycle, thinned, and unthinned) and to either heavier (open to tracked vehicles) or lighter (primarily dismounted infantry) military use.

Thirty-two 400m x 400m field research sites were established during FY00 in upland forest areas that had been burned during Spring 2000. Half the sites are on sandy soil; half are on clayey soil. Half the sites (8) on each soil type are in areas with heavier military use; half are in areas with lighter use. Half the sites (4) in each soil type/military use combination were burned on a 2-yr cycle in Spring 2002; half will have burning delayed until Spring 2004. Each combination of soil type/military use/burning includes two sites that were recently thinned and two that are unthinned.

8.2 Summary of Research Activities and Results for FY03

Research efforts during FY03 concentrated on collecting field data to compare biogeochemical cycling and vegetation between 2-yr burn sites (now in the second post-burn season) and 4-yr burn sites (now in the fourth post-burn season) on sandy and clayey soils in heavier and lighter military training compartments. In addition, a manuscript reporting results of surveys (2001 – 2002) that compared initial edaphic conditions among the 32 sites was submitted for publication.

8.2.1 Edaphic conditions

Initial (2001) soil conditions among the sites reflect natural variation and effects of past land use. To assess these conditions, we characterized mass, carbon content, and nitrogen content of the soil organic layer; extractable nitrogen content of the mineral soil; and potential available nitrogen in all 32 Savannah River Ecological Laboratory (SREL) sites. Plant root simulator probes and pot micro lysimeters were deployed in four sites (two with sandy soil and two with clayey soil).

Average dry mass of the organic (O) layer was greatest in sites with clayey soil (C) and lighter military use (L) and lowest in sites with sandy soil (S) and heavier military use (H); df=3, f=3.04, p<0.0298; Table 8-1). These results likely reflect tree density on the sites.[1] The O layer nitrogen pool also was greatest in light use-clayey (LC) sites (Table 1; df=3, f=2.75, p<0.0040). Figure 8-1 summarizes the results for nitrogen cycling in sandy sites compared to clayey sites.

Table 8-1. Mean and (standard error) of organic layer mass, organic layer (O.L.) nitrogen content of 32 forest stands grouped into four categories.

	LC	HC	LS	HS
O.L. Mass (g/m^2)	**1165.2**$_a$ (100.5)	931.0$_{ab}$ (74.6)	922.8$_{ab}$(96.7)	**807.7**$_b$ (100.6)
O.L. % Nitrogen	0.75$_a$ (0.03)	0.65$_a$ (0.02)	0.73$_a$ (0.02)	0.70$_a$ (0.02)
Nitrogen Pool ($g N/m^2$)	**8.68**$_a$ (0.93)	6.02$_b$ (0.47)	6.92$_{ab}$ (0.75)	6.07$_{ab}$ (0.96)

Lower case subscripts indicate significant differences among categories (P<0.05).

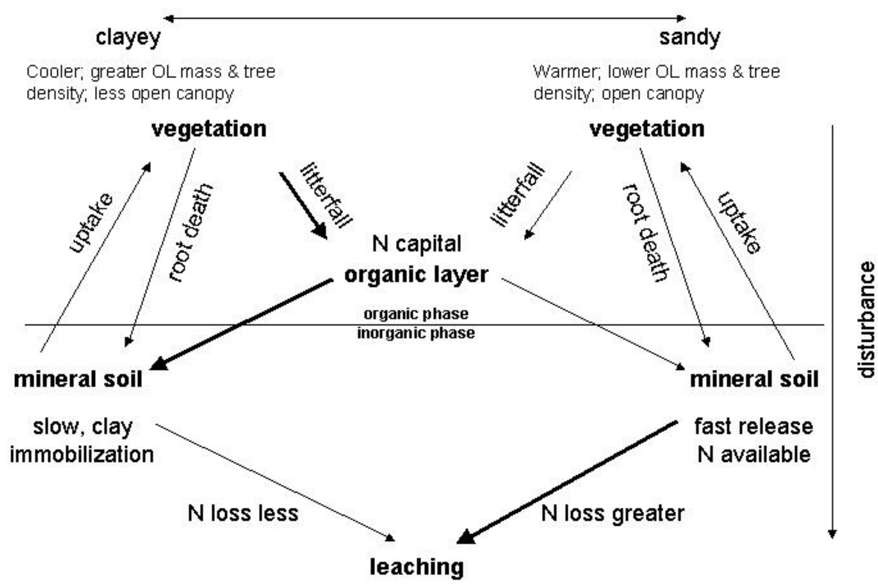


Figure 8-1. Nitrogen cycling in sandy and clayey soil, and response to disturbance. Arrow thickness indicates relative amount of nitrogen.

[1] Dilustro, J.J., B. Collins, L. Duncan, and R. Shartiz. 2002. Soil Texture, land use intensity, and vegetation of Ft Benning upland forest sites. Journal of the Torrey Botanical Society 129(4):280-297.

The lower-quality organic layers in sandy sites could immobilize nitrogen through relatively slow rates of decomposition and nitrogen release to the mineral soil. In the mineral soil, field and laboratory results suggest that mineralization processes enhance nitrogen availability in sandy sites, especially in land compartments with heavier military training. In laboratory incubations, mineral soils from the sandy sites in compartments with heavier military use produced significantly more NO_3-N, which suggests mineralization processes differ in these sites (soils from other sites produced less NO_3-N and more NH_4-N) and there is greater potential for nitrogen to leach from the site or be available for vegetation after disturbance. Results from the laboratory mineralization studies and plant-root-simulator probes also indicate greater nitrogen production and availability in sandy compared to clayey sites. Although longer-term monitoring indicates nitrate leakage is relatively low over all SREL sites, small export events may be greater in sandy sites (Figure 8-2).

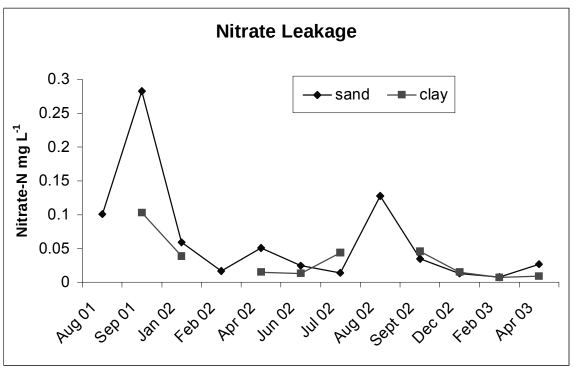


Figure 8-2. Soil water nitrate concentration as measured via soil lysimeters installed below the dominant rooting zone in sandy and clayey sites (n=2, 12 lysimeters per site).

In contrast to the sandy sites, greater organic layer mass and initial extractable mineral soil nitrogen in clayey sites, particularly in sites with lighter military use, reflect the effects of finer soil texture and the lower impact of military training on the loss of the organic layer (Figure 8-1). Greater organic layer mass and nitrogen content favor faster decomposition and release of nitrogen for mineralization in these sites, but the lower nitrogen availability we observed in the field suggests mineralized nitrogen can be bound by fine soil particles. Additional factors such as soil type and litter composition may influence N processing on these sites. Despite the greater organic layer mass and nitrogen content on the clayey sites with lighter military use, these sites had the lowest net nitrification and percent relative nitrification rates.

Additional data collected during 2002 and 2003 are being used to characterize edaphic conditions that can affect nitrogen cycling and response to disturbance among the SREL sites. Preliminary data suggest root production is greater in sandy compared to clayey soil (Figure 8-3). This could be related to greater nitrification and nitrogen availability, or more limited soil moisture, in sandy sites. Soil respiration, a measure of root and microbial activity, is influenced by soil temperature (Figure 8-4). Over a year, seasonal soil temperature fluctuations are greater at 40 cm than at 1 m depth (Figure 8-4). Comparisons of temperature curves at different depths will identify any differences in soil profile temperature flux across SREL sites of differing soil texture. These differences could result in differences in biological activity, including respiration and root production among sites.

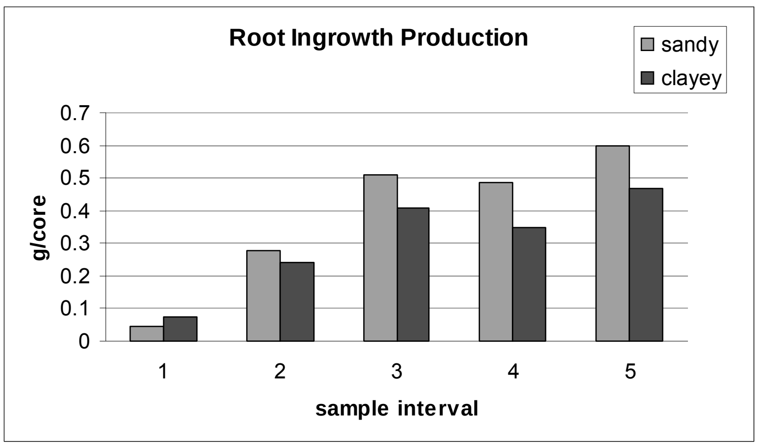
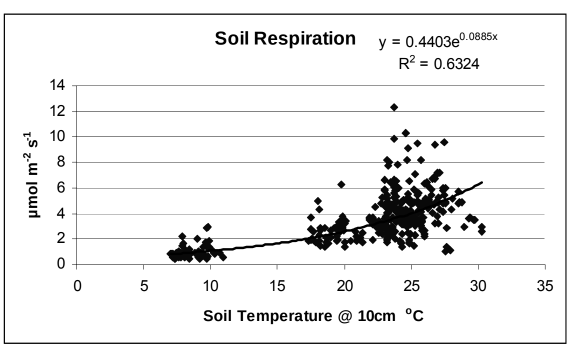


Figure 8-3. Root production (g/core) measured via the root ingrowth technique in sandy and clayey sites (n=4) from 2002 to 2003.
These data are preliminary; samples are currently being ashed and corrected for contamination.



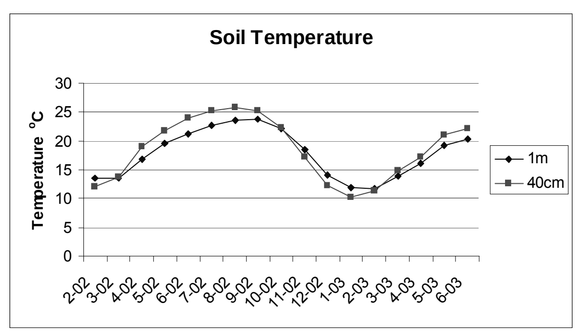


Figure 8-4. The relationship of soil respiration, as measured by infrared gas analyzer on eight sites of varying soil texture in 2002 and 2003, and soil temperature, fit by exponential regression.
Over a year, soil temperature at 40 cm and 1 m in a representative site fluctuate.

8.2.2 Fire effects

Maximum soil temperatures during the low-intensity prescribed fires in 2001 ranged from 15 °C to 43 °C among sites. The duration of elevated temperature varied among and within sites; the site with the longest elevated temperature, D16C, was the only site in which the fire was ignited before noon. As shown in Figure 8-5, the fires caused a small, but significant, decrease in mass of the organic layer. Among sites, consumption ranged from 2% to 36% of pre-fire organic layer mass.

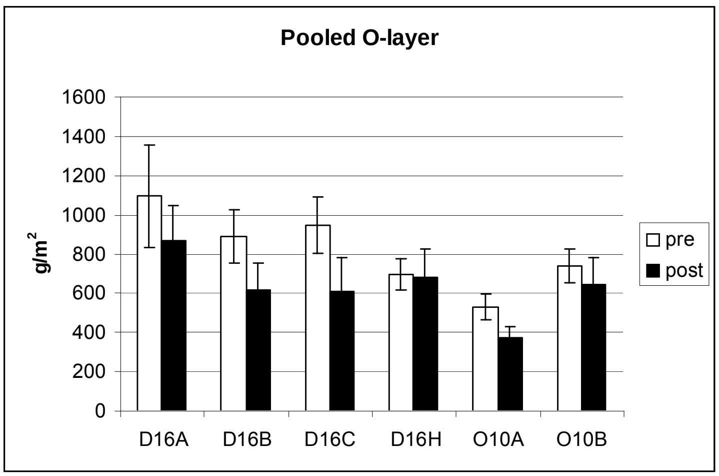
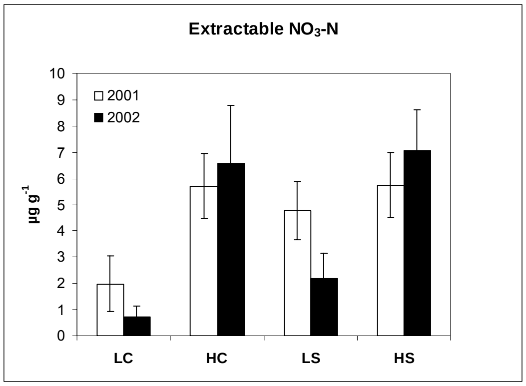


Figure 8-5. Average mass of the organic layer before and after a prescribed fire.

Immediate (< 3 wk) fire effects on soil nutrients varied, with a general trend of no significant effect on extractable mineral soil N or Al, and increase in Ca. Over two to three seasons, the prescribed fires influenced nitrogen cycling. As shown in Figure 8-6, NH_4-N generally increased the growing season following burning. NO_3-N increased following fire in stands with heavier military use, but decreased in sites with lighter, predominantly dismounted infantry, training. As shown by the greater mass in 2003 (Figure 8-7), post-fire recovery of the pooled organic layer was faster in sites with lighter military training.

We compared aboveground biomass of vegetation categorized as ferns, forbs (herbs other than grasses), grasses, woody species < 4 cm stem diameter, legumes, and standing dead between burned and unburned sites with sandy and clayey soil. In 2002, woody species biomass was greater on unburned, compared to burned, sites ($P = 0.0013$; Figure 8-8). In 2003, grass biomass was greater on burned than unburned sites ($P = 0.03$; Figure 8-8). Grass biomass also was greater on clayey sites compared to sandy sites in both 2002 ($P < 0.001$) and 2003 ($P = 0.0015$; Figure 8-8). Legume biomass was greater on clayey sites than sandy sites ($P = 0.0255$) and differed between years ($P < 0.0001$; Figure 8-8).



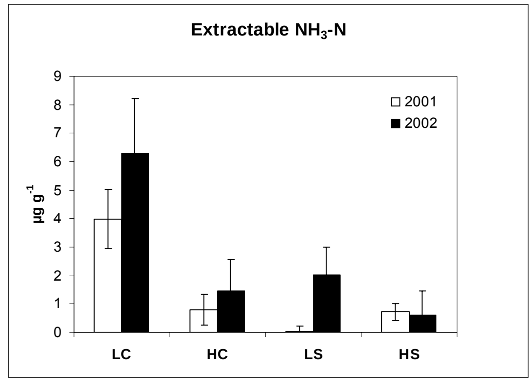


Figure 8-6. Extractable mineral soil nitrate- and ammonium-nitrogen before (2001) and after (2002) prescribed fire.

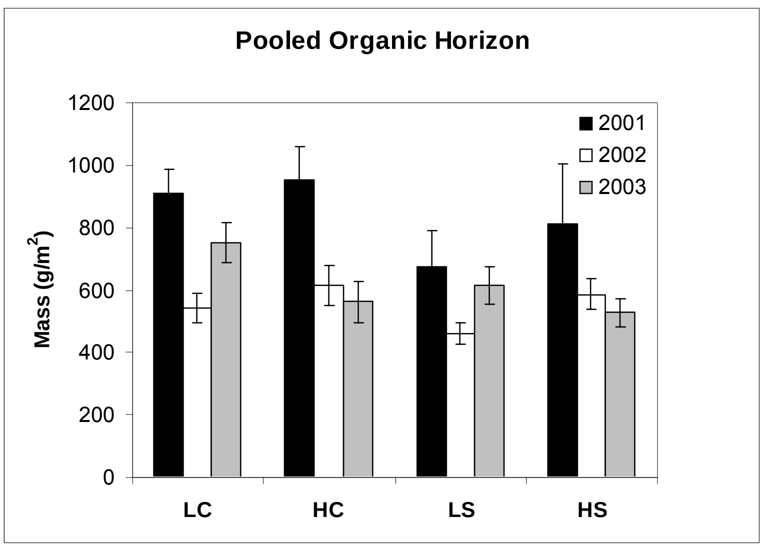


Figure 8-7. Mass of the pooled organic horizon in sandy (S) and clayey (C) sites with lighter (L) or heavier (H) military training before (2001) and the first (2002) and second (2003) seasons after prescribed fire.

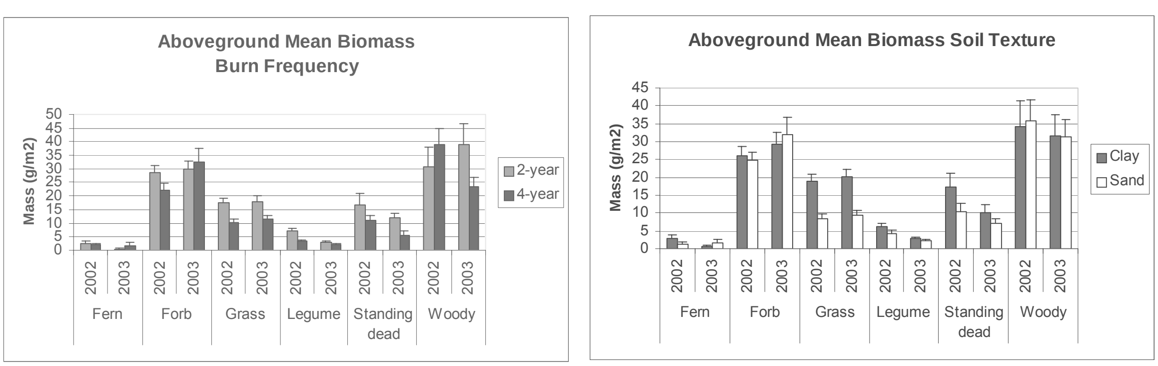


Figure 8-8. Plant aboveground biomass compared between unburned (4-year) and burned (2-year) sites and between sites with sandy and clayey soil.

During the 2003 growing season we measured nitrogen fixation activity of the dominant legumes in 16 of the research sites (Figure 8-9). We extrapolated fixation per area and converted from nodule to aboveground biomass via conversion factors generated from multiple whole plant and nodule harvests per species. The conversion was then applied to data from groundlayer vegetation harvests to generate fixation input per unit area. These estimates represent maximum potential fixation inputs by these legume species in sites burned in 2002 (2-year) or left unburned until 2004 (4-year).

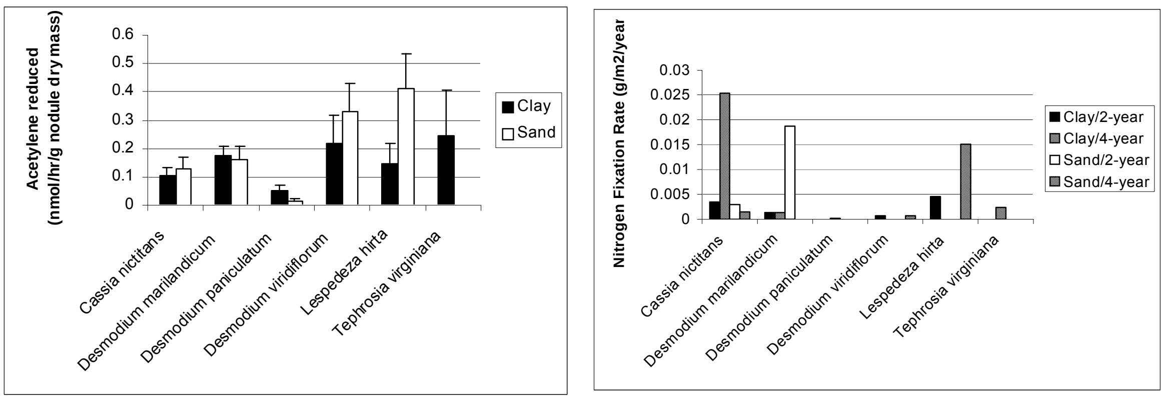


Figure 8-9. Nitrogen fixation activity, as measured by acetylene reduction, of legume species in sandy and clayey sites, and estimates of nitrogen fixation rates by these species measured in 2003.
All sites were burned in 2000; 2-year sites were burned over winter before the 2002 growing season; 4-year sites were left unburned.

In 2003 we developed a model from our field studies to predict N transformations and ANPP (biomass) of groundcover components under differing burn frequencies (Figure 8-10). Preliminary model runs revealed a trend for higher levels of soil organic N, aboveground groundlayer N, root N, and soil NO_3- and NH_4+ with a 2-year versus a 4-year burn interval. These results are expected and suggest the model accurately predicts N transformations. After completing the analysis of nitrogen fixing activity of legumes, the estimate of nitrogen fixation rates based on harvested legume biomass is considerably lower than the values used in the original model. We are in the process of recalibrating the model using our field measured fixation activity.

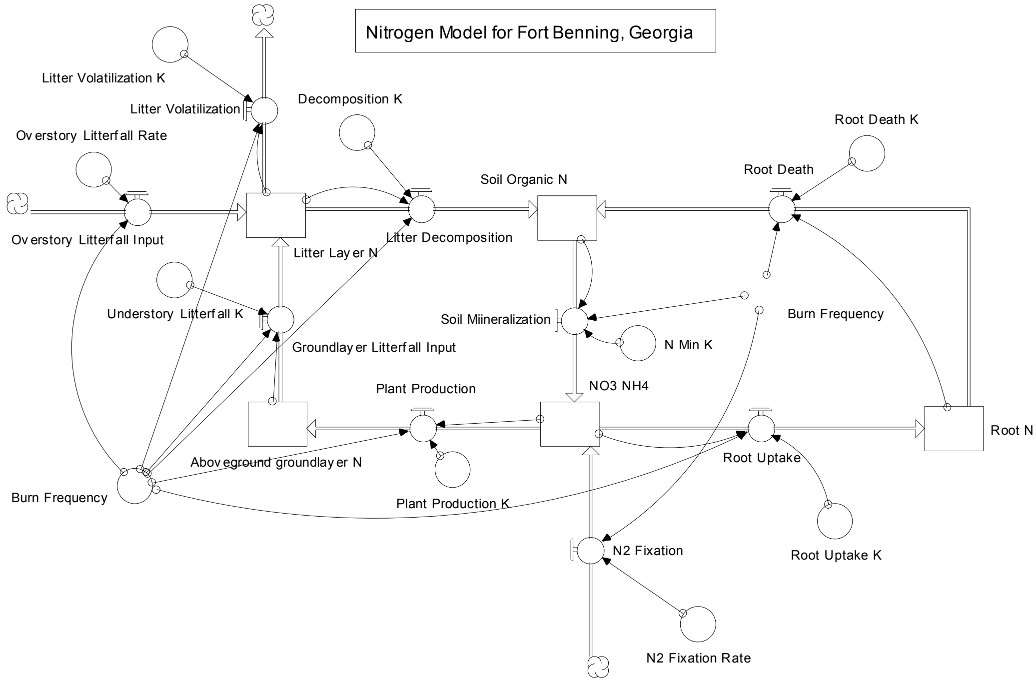


Figure 8-10. STELLA model of nitrogen cycling under different burn frequencies at Fort Benning.

8.3 Important Findings and Conclusions

Field observations reveal that both fire and soil texture influence post-fire ground layer vegetation in the SREL sites at Fort Benning. Biomass of grasses and nitrogen-fixing legumes was found to be greater on clayey, compared to sandy, soil. Fire caused a decrease in biomass of woody species, and an increase in grass biomass in both the first and second post-fire seasons. However, effects of prescribed fire and military training on forest soil biogeochemistry at Fort Benning depend on the temporal scale at which they are evaluated. Initial conditions in our sites suggest, over the scale of decades, military training with tracked vehicles can reduce soil quality, especially on sandy sites. Low-intensity prescribed fire appears to have little immediate effect on soil conditions, but may result in an increase in available NH_4-N the first post-fire growing season. Heavier military use may slow soil recovery during the 2-3 season intervals between prescribed fires. SREL research is incorporating multiple temporal scales to help characterize short-term trajectories of ecosystem response to land use disturbance within the longer-term trajectories and identify thresholds of cumulative impacts of land use over time. In addition, further development of the nitrogen cycling model can help resource managers predict thresholds associated with nitrogen cycling under different prescribed fire frequencies and land use conditions at Fort Benning.

8.4 Products

8.4.1 Presentations

Crawford, C. B., J. J. Dilustro, and B. S. Collins, and L. Duncan 2003. Soil response to prescribed fire in mixed pine-hardwood forests at Ft. Benning, GA. Ecological Society of America annual meeting, Savannah, GA. August.

Dilustro, J. J., Beverly S. Collins, and Lisa K. Duncan. 2003. Soil nitrogen cycling in mixed forests of varying soil texture at Fort Benning, Georgia. Ecological Society of America annual meeting, Savannah, GA. August.

Drake, S. J., R. R. Sharitz, J. J. Dilustro, and B. S. Collins. 2003. A model for predicting C and N transformations and annual net primary productivity under differing burn frequencies in a southeastern mixed pine-hardwood forest. Ecological Society of America annual meeting, Savannah, GA. August.

Duncan, Lisa K., John J. Dilustro, and Beverly S. Collins. 2003. Avian response to forest management and military training at Fort Benning, Georgia. Ecological Society of America annual meeting, Savannah, GA. August.

Collins, B., J. Dilustro, and L. Duncan. 2003. Thresholds of disturbance and dynamics of mixed pine-hardwood forests at Fort Benning, GA. SE Biology 50:150.

Drake, S. J., R. R. Sharitz, J. D. Dilustro, and B. Collins. 2003. Aboveground peak biomass and groundcover plants in a mixed pine forest on sites with differing soil textures and burn frequencies. SE Biology 50:191.

Dilustro, J. J., B. S. Collins, and L. Duncan. 2003. Short-term response of soil to prescribed fire in mixed pine forests on Ft. Benning, Georgia. SE Biology 50:191.

Collins, B. and J. Dilustro. 2002. What's going on at Fort Benning? SREL, November (presentation)

Collins, B., J. Dilustro, L. Duncan, and R. Sharitz. 2002. Thresholds of land use in upland forests at Fort Benning. SERDP Partners in Environmental Technology Technical Symposium, Washington, DC, December. (poster)

8.4.2 Papers

Submitted

Dilustro, J.J., B. Collins, and L. Duncan. Soil Nitrogen Availability in Fall Line Mixed Pine Forests. Southeastern Naturalist.

9 SEMP Integration Task

Virginia Dale and Amy K. Wolfe, Oak Ridge National Laboratory (ORNL)
Aaron Peacock, University of Tennessee
Jeff Fehmi, Construction Engineering Research Laboratories

9.1 Background

Over the past five years, SEMP has initiated three indicator studies and two threshold studies. In addition, the design phase of the Ecological Characterization and Monitoring Initiative (ECMI) has been completed. Furthermore, Fort Benning has now completed its Integrated Natural Resource Management Plan (INRMP). At this juncture it was appropriate to evaluate these three components and begin to integrate them. The purpose of integration is to ensure that the components are complementary and interconnected and that, in sum, they improve environmental management. Other goals are to foster communication among the research teams and to ensure they are a part of the integration effort.

9.2 Approach

Figure 9-1 shows the general plan for integration. The first step was to query the three indicator and two threshold research teams as to what their proposed indicators are. (This approach assumes that the threshold projects are a special case of the indicator work in examining threshold conditions of particular indicators.) The formal query asked for details of each proposed indicator (e.g., the spatial and temporal resolution, how it is measured and interpreted, etc).

The second step was to conduct a preliminary screening of the proposed indicators against the criteria for indicators set forth by Dale and Beyeler[1] based on their review of the indicator literature. Other studies and approaches developed since the 2001 review also were considered for the criteria, such as the new book

[1] Dale, VH and Beyeler, SC. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1: 3-10.

on *Monitoring Ecosystems*.[2] For another example, the survey of biodiversity indicators of forest sustainability conducted by the Manomet Center for Conservation Sciences provides a way to categorize types of indicators. It is not our intent to develop a single metric of ecological integrity but rather to explore a suite of metrics that is useful for management issues at Fort Benning (and hence, potentially at other military installations). Even so, information proposed to evaluate candidate metrics[3] may be useful in evaluating the suite. Comments from the five research teams, the environmental management staff at Fort Benning, and the Technical Advisory Committee were useful in finalizing the criteria for relevance and feasibility of the suite of ecological indicators. The final list of ideal criteria is given in Table 9-1.

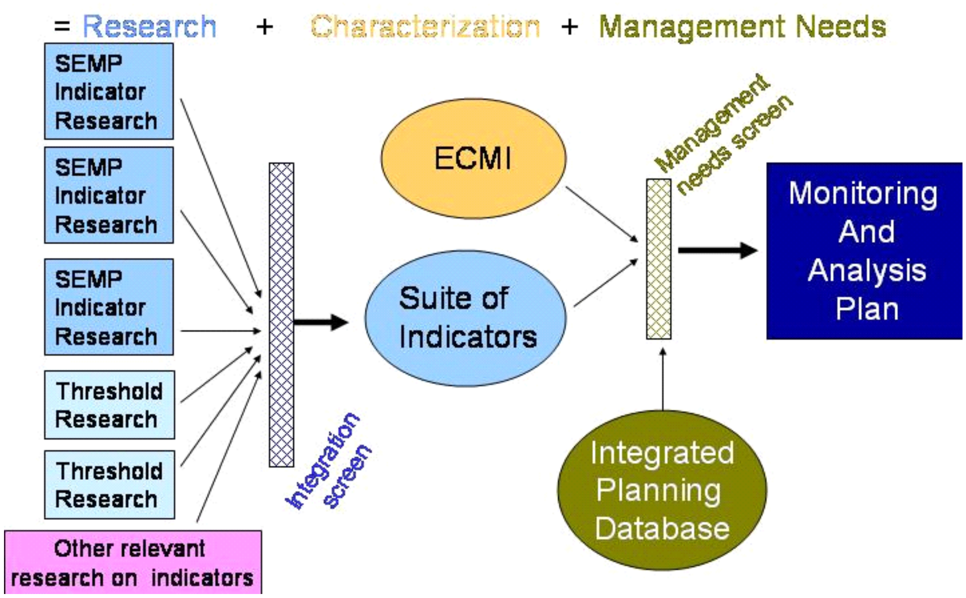


Figure 9-1. Integration plan.

[2] Busch, DE and Trexler, JC. 2003. Monitoring Ecosytems: Interdisciplinary Approaches for Evaluating Ecoregional Initiatives. Island Press, Washngton DC, 447 pages.

[3] Andreasen, JK, O'Neill, RV, Noss, R, and Slosser, NC. 2001. Considerations for the development of a terrestrial index of ecological integrity. Ecological Indicators 1: 21-35.

Table 9-1. Criteria for Ideal Set of Indicators.

(based on Dale, VH and Beyeler, SC. 2001. Challenges in the development and use of ecological indicators. Ecological Indi-cators 1: 3-10)

•	Are easily measured
•	Are sensitive to stresses on system
•	Respond to stress in a predictable manner
•	Are anticipatory: signify an impending change in the ecological system
•	Predict changes that can be averted by management actions
•	Have a known response to natural disturbances, anthropogenic stresses, and changes over time
•	Have low variability in response
•	Are integrative: the full suite of indicators provides a measure of coverage of the key gradients across the ecological systems (e.g., soils, vegetation types, temperatures, etc.)
To determine these indicators, the team should:	
•	Select indicators that are broadly applicable across the system of interest and to other ecological systems
•	Consider the spatial and temporal context of measure

This screening step requires assessing the data against the criteria. In some cases, the screening will involve decisions as to whether the criteria are met or not. Review of these decisions by the five research teams and Fort Benning staff will be useful. The screening will also require a series of multivariate analyses to determine which set of indicators characterizes differences among prior land-use practices (as is described below). This screening is still in process.

Before the analyses of indicators can be conducted, land-management categories were determined. The determination required each of the research teams to first agree upon a set of land-management categories. These land-management categories are listed in Table 9-2 and described in *Appendix 1* (page 157). The Delphi method was used to agree on the specific categories. The Delphi technique is a means of achieving consensual validity among raters by providing them feedback regarding other raters' responses.[4] A report describing this process was delivered in October 2003.

Once the land-management categories were determined, each team assigned a category to each plot based on direct observations and on information provided

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[4] Gokhale, AA. 2001. Environmental initiative prioritization with a Delphi approach: A case study. Environ. Manage. 28 (2): 187-193; Mendoza, GA, Prabhu, R. 2000. Development of a methodology for selecting criteria and indicators of sustainable forest management: A case study on participatory assessment. Envir. Manage. 26 (6): 659-673; Nagels, JW, Davies-Colley, RJ, and Smith, DG. 2001. A water quality index for contact recreation in New Zealand. Water Sci. Technol. 43 (5): 285-292.

by Fort Benning staff. This information was submitted by each SEMP research team to Oak Ridge National Laboratory in November 2003.

The land-management categories will be treated as dependent variables in a multivariate analysis of the proposed indicators that make it through the first screen. In the case of similar indicators but different data collection methods, the method of collection will be treated as a random effect in the model. Those indicators that, based on the multivariate analyses, best explain the land-management categories will constitute the suite of indicators shown in Figure 9-1. An example of this approach, based on a subset of indicator data, was presented to the research teams and the TAC in the Fall of 2003. The full data set is now being prepared for analysis.

The second screen focuses on management needs. These needs are defined by the components of the “Dynamic Planning Toolbox,” which includes the Integrated Natural Resource Management Plan (INRMP), the range plan, the installation master plan, and long–range planning efforts of headquarters (Figure 9-2). Dr. Jeff Fehmi has circulated several versions of a draft report addressing management needs.

The final result of this combined screening and analysis effort will be a monitoring and analysis plan that includes a list of measures, protocols for obtaining data, and suggested means of analyzing the data. Dr. Fehmi has already put in place the steps necessary for developing this monitoring and analysis plan and interfacing with the management team at Fort Benning. The monitoring and analysis plan must support the diversity of activities on an installation (Figure 9-3. Environmental management objectives must mesh with the installation’s military training and testing missions. Together, these missions determine the nature and extent of installation activities, which, in turn, typically have some environmental impacts. These impacts will be measured in accordance with the monitoring and analysis plan, so that measures of impacts can be interpreted in view of larger environmental objectives. Specific environmental objectives may change in response to observed impacts, especially in the short term. However, higher order environmental goals for the installation are likely to be more durable and less prone to alteration.

Table 9-2. Land managementuse categories as determined by military training and land management practices (September 12, 2003).

Key ‘0’ = *military uses* do NOT occur in areas managed in specified ways.
‘I’ and ‘F’ = the relative frequency with which *military uses* occur in areas managed in specified ways (I = infrequent and F = frequent).
‘+’ = *land management* options in areas not used by the military.

Land management goals and endpoints	Cause of predominant ecological effect from military use(s) of land								
	Tracked vehicles	**Wheeled vehicles**	**Foot traffic**	**Designated bivouac areas**	**Firing ranges**	**Impact areas**	**Drop or landing zones**	**No military effect**	**Admin use**
1. Minimally managed areas									
1.1 Wetlands	I,F	I, F	I	0	0	0	0	+	0
1.2 Vegetation on steep slopes	I, F	I, F	I	0	0	0	0	+	0
1.3 Forests in impact zones	0	0	0	0	0	I,F	0	+	0
2. Managed to restore and preserve upland forest									
2.1 Upland forests 2.1.a Long leaf dominance 2.1.b Mixed pine 2.1.c Scrub oak pine mix	I	I,F	I, F	0	0	0	0	+	0
2.2 RCW mgmt clusters	I	I	I,F	0	0	0	0	+	0
2.3 Sensitive area designated by signs	0	0	I,F	0	0	0	0	+	0
3. Managed to maintain an altered ecological state									
3.1 Intensive military use areas	F	F	0	I,F	F	0	0	0	0
3.2 Wildlife openings	0	I	I	0	0	0	I	+	0
3.3 Mowed fields	0	I	I,F	0	I,F	0	I,F	+	0
3.4 Roads (paved and unpaved)	I, F	I, F	I, F	0	0	0	0	+	0
3.5 Built environment	0	0	0	0	0	0	0	0	+

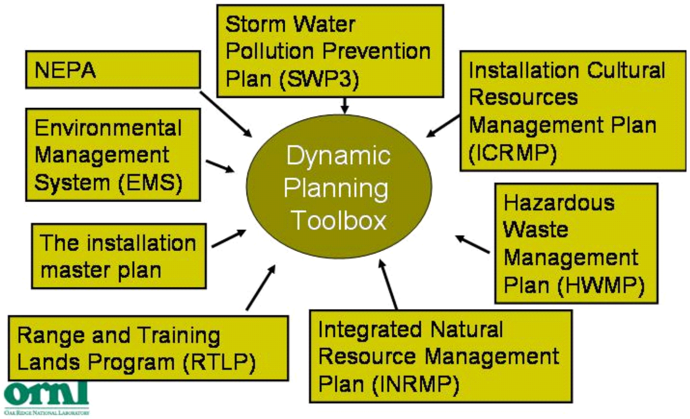

Figure 9-2. Components of the Dynamic Planning Toolbox.

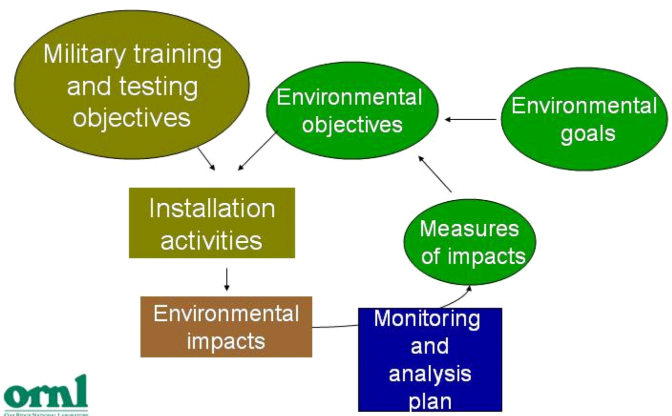

Figure 9-3. The monitoring and analysis plan.

9.3 Discussion

Developing a land-management category matrix that both SEMP ecological researchers and Fort Benning land managers found acceptable proved a more involved and challenging process than initially anticipated. Members of each researcher and land manager group have different perspectives and research- or practice-oriented goals, so achieving consensus within a group was challenging on its own. This difficulty was compounded by simultaneously seeking consensus among and between SEMP researchers and Fort Benning land managers in a two-part, but intertwined, integration process. Given the evolving and uncertain state of the ecological science, and the intent to assure that the best available science is used in land management application, we do not see an easier alternative. Seeking consensus only among researchers could provide a suite of land-management categories that are technically accurate but do not meet the needs of practitioners. Similarly, consensus among land managers may fail the test of scientific credibility.

This portion of the larger SEMP integration effort began after the five ecological indicator and threshold projects were well underway; some were drawing to an end. One might argue that post-hoc integration is a less efficient process, with less effective outcomes, than proactive integration initiated early in the scientific research process. The rationale behind this argument might be that minimizing the mismatch between science and application at the beginning of research programs would maximize the practical usefulness of the resulting science. Such a hypothesis would be extremely difficult to test in real-world conditions. However, we suspect that it would be a mistake to treat early integration like an intervention that, alone, would assure the meshing of scientific data, models, and results with practitioners' needs. Achieving consensus early in the implementation of a research program may shift the starting point for research projects to a point where they have the potential to meet practitioners' needs. However, such an approach ignores the evolving nature the scientific enterprise. The conduct of individual projects often is subject to modification, for example as scientists encounter unforeseen circumstances in the field or develop new understandings. Further, adjustments may be made in response to interactions with other researchers who are working on related projects, perhaps under the same research program. The specific path researchers take during the course of their research project may not be entirely predictable early on. Results, therefore, may or may not mesh with practitioners' needs.

Just as the scientific enterprise evolves, so does the land management enterprise. Change within both science and practice is predictable in general, though the specific nature of the changes may not be predictable. Anticipating change, though, suggests a model for achieving integration between science and practice that avoids the pitfalls both of the post-hoc approach we took and of an early intervention approach. This model would emphasize continuing, integration efforts. Pragmatic considerations likely dictate that "continuing" should be translated as "periodic" integration in which researchers and practitioners address—and ideally achieve consensus on—clearly defined issues that arise over the course of an applied research program. This approach is compatible with an adaptive management model, but it explicitly provides a mechanism for incorporating the best available and evolving scientific knowledge.

9.3.1 Acknowledgement

We appreciate the assistance of many people who helped with this study. Robert Addington, Beverly Collins, John Dilustro, Charles Garten, Thomas A. Greene, Anthony Krzysik, Robert Larimore, Maureen Mulligan, Joseph Prenger, and Peter Swiderek participated in the discussions. Jeffrey Fehmi, Bill Goran, Hal Balbach, and Hugh Westbury provided encouragement and support.

Appendix 1: Descriptions of Proposed Land-management Categories at Fort Benning for the SEMP Integration Plan

Military uses (Cause of predominant ecological effect from military use(s) of land)

Attributes of military uses of land can influence the ecological effects of those land uses significantly. As examples, the type of traffic (tracked, wheeled, or foot) and frequency of use may make the biggest differences in ecological impact. Therefore, it is important to consider these attributes in conjunction with the military uses, themselves, to understand ecological conditions and support land management decision making.

- TRACKED VEHICLES occur both on and off roads. Down-slope impacts of sedimentation from tracked vehicles can occur.
- WHEELED VEHICLES can occur on road or other areas. In many areas, impacts from other tracked vehicles are more intensive than from wheeled vehicles.
- FOOT TRAFFIC can occur throughout much of the installation but in some areas impacts from other military uses are more intensive than from foot traffic.
- DESIGNATED BIVOUAC AREAS occur anywhere assigned for soldiers to stay overnight. These areas are prepared and may or may not be located in conjunction with ranges. Bivouac areas are affected by wheeled vehicle and foot traffic on a regular basis and include such other activities as digging, tenting, etc. With regard to frequency, all designated bivouac areas are used on a regular basis; this category does not include undesignated areas where soldiers may stay occasionally. Although bivouac areas generally are heavily impacted, they tend not to be subject to directed land management actions.
- FIRING RANGES generally are kept either clear of vegetation or covered by low-growing vegetation. Thus, the two main management activities at ranges are maintenance (grading, putting up targeting, etc.) and vegetation control (fires—maybe naturally occurring, mowing, herbicides). Frequency also is an attribute of firing ranges; some ranges are used almost daily whereas others are not used as much (it is possible to obtain data on frequency of use of each range). Ranges are managed differently depending on

whether or not they are used heavily (for example, frequently used ranges have firebreaks to reduce the potential of fire to spread).

- IMPACT AREAS are places in which unexploded ordnance is found. Therefore, essentially no management occurs in these areas, although resource managers may enter them for such activities as woodpecker work. The intensity and/or frequency of munitions within different portions of impact areas are highly variable. Hence, the attribute of frequency is useful for understanding and assessing impact areas. Impact areas with frequent use are the dud areas, and those with infrequent use are the buffers. In any case, people cannot enter an impact area without special permission.
- DROP OR LANDING ZONES are open fields created for parachutists to land. These areas are affected by wheeled vehicle and foot traffic. Infrequently used drop zones support wildlife openings, and are thus also affected by mowing, disking, planting, and other activities associated with wildlife openings. Landing Zones for helicopters are slightly different from drop zones. Landing zones are used less frequently and are impacted by aircraft weight and heat. Some landing zones are planted wildlife openings, but all of the drop zones are mowed fields.
- AREAS WITH NO MILITARY TRAINING may be within impact areas or outside of them.
- ADMINISTRATIVE AREAS that represent the cantonment.

Land management goals

"Land management goals" provide a long-term orientation for the integration effort. These goals tend to be more stable than either specific management practices undertaken in particular areas (e.g., thinning or logging) or land cover types. Therefore, categorizing land areas within Fort Benning according to land management goals is efficacious. Designated "unique ecological areas" can occur in several categories.

Different goals can involve a variety of land management activity, ranging from minimal to intensive. Much of the military reservation is managed minimally. Land management practices at Fort Benning vary according to their focus on:

1. MINIMALLY MANAGED AREAS—include places where no active management occurs (in contrast with intensive, active management), and where the management goal is simply to minimize disturbance and keep the area ecologically intact.
    - 1.1 Wetlands —includes floodplains and bottomland hardwood forests where no timber is harvested
    - 1.2 Vegetation on steep slopes—where abrupt topography limits management

1.3 Forests in impact zones—where no management occurs because access is restricted.

2. MANAGED TO RESTORE AND PRESERVE UPLAND FOREST—currently the most common land management type for upland pine forests at Fort Benning. These areas are managed with the goal of restoring and maintaining uneven-aged longleaf pine forests and mixed longleaf pine-scrub oak woodlands. This goal is achieved via a combination of management practices, including timber harvesting, reforestation and prescribed fire. Most of the acreage in upland forested areas is designated as “Typical management areas.” However, “RCW clusters” and “Sensitive area signed areas” are separated here because management practices in these areas may be slightly different. For example, cut-to-length forestry may be used over conventional forestry in RCW clusters because it is less destructive to the understory plant community.

2.1 Upland forest areas—includes all of the upland forested areas that are not designated as RCW clusters or sensitive areas. These areas include stands dominated by long leaf pine, mixed pine stands, and scrub oak and pine mix.

2.2 RCW (red cockaded woodpecker) management clusters—Signed areas that contain RCW cavity trees.

2.3 Sensitive areas designated by signs—those sites designated by signs as being sensitive to human disturbance and include areas with gopher tortoise, archeological ruins, and sensitive plants.

3. MANAGED TO MAINTAIN AN ALTERED ECOLOGICAL STATE—includes areas where the land management goal is to maintain an altered ecological state, either for the purpose of military training or for some other stated purpose such as enhancing wildlife or wild-game populations. Erosion control areas are also included here, and the goal for these areas is simply to stabilize the erosion. Erosion control projects are generally short-term. Management to maintain an altered ecological state includes several subcategories:

3.1 Intensive maneuver areas—support intensive military use and often are associated with mechanized operations. These areas are sometimes referred to as “sandbox” or sacrifice areas, for they have only limited management.

3.2 Wildlife openings—can be cultivated with crops of special value to wildlife for either cover or forage. Sometimes these areas are mowed.

3.3 Mowed fields—cut regularly to maintain grasses and other low-growing vegetation.

3.4 Roads—Both paved and unpaved roads and a small buffer area around them.

3.5 Built environment—Buildings and open areas associated with the cantonment.

Combination of military use and land management

A matrix of all possible combinations of military land use with land management (Table 9-3) shows 54 possibilities for Fort Benning. Of these possibilities, three types are in erosion control areas. While discussion participants anticipated that distinguishing "frequent" from "infrequent" military use would be valuable, they suggested evaluating the value of the distinction as the SEMP Integration exercise progresses. Furthermore, it is apparent that both military use and management goal categories are important to know because they differ in cause and effect. It is essential for the integration effort that each SEMP research team's field sites be identified with a unique land-management category. At the present time, however, researchers may need to confirm with Fort Benning staff (especially Pete Swidereck) the correct categorization of their sites. Identification can be based on location together with knowledge of land cover, patterns of military use, and land management practices for Fort Benning.

Table 9-3. Codes for land-use categories as determined by military training and land management practices.

Land management goals	Cause of predominant ecological effect from military use(s) of land								
	Tracked vehicles	**Wheeled vehicles**	**Foot traffic**	**Designated bivouac areas**	**Firing ranges**	**Impact areas**	**Drop zones**	**No effect**	**Administrative use**
1. Minimally managed areas									
1.1 Wetlands	WetTrI WetTrF	WetWhI WetWhF	WetFtI	0	0	0	0	Wet+	0
1.2 Vegetation on steep slopes	SteTrI SteTrF	SteWhI SteWhF	SteFtI	0	0	0	0	Ste+	0
1.3 Forests in impact zones	0	0	0	0	0	ForImpI ForImpF	0	For+	0
2. Actively managed to restore and preserve upland forest									
2.1 Upland forest	UpltrI	UplWhI UplWhF	UplFtI UplFTF	0	0	0	0	Upl+	0
2.2 RCW mgmt clusters	RcwTrkI	RcwWhI	RcwFtI RcwFtF	0	0	0	0	Rcw+	0
2.3 Sensitive area designated by signs	0	0	SenFtI SenFtF	0	0	0	0	Sen+	0
3. Managed to maintain an altered ecological state									
3.1 Intensive military use areas	MilTrkF	MilWhF	0	MilBivI MilBivF	MilFirF	0	0	0	0
3.2 Wildlife openings	0	WldWhI	WldFI	0	0	0	WldDrpI	Wld+	0
3.3 Mowed fields	0	MowWhI	MowFtI MowFtF	0	MowFirI MowFirF	0	MowDrpI MowDrpF	Mow+	0
3.4 Roads (paved and unpaved)	RdtrI RdTrF	RdWhI RdWhF	RdFtI RdFtF	0	0	0	0	Rd+	0
3.5 Built areas	0	0	0	0	0	0	0	0	Ba

10 Site Comparison Indices

Dr. Harold E. Balbach, ERDC/CERL
Dr. Anthony J. Krzysik, Prescott College

After the research teams involved in this study had been working for almost 2 years, about when they were reporting on the results of their first full year of results, it became clear that the initial characterization of their study sites into areas of "low," "moderate," and "high" disturbance was too imprecise to allow cross-project comparisons of impact.

It was not difficult to agree on certain conditions. For example, Figure 10-1 shows evidence of heavy disturbance. It was much more difficult for the (subjective) assignment of original condition to reach consensus when different teams had visited different locations at different times. This meant that, while a team might well be able to compare conditions between its different study sites, comparison among the different teams was seriously compromised. In retrospect, this was a fault that might have been foreseen, but was not. Further, the question then arose of how to compare new study sites with previous sites in any uniform sense. As a result, in mid-year 2002, the SEMP Technical Advisory Committee created guidelines they recommended be followed to create a composite index that was capable of ranking study sites on a common scale (Table 10-1).

Figure 10-1. An example of a SEMP study site where it could be agreed that disturbance was extremely high.

Table 10-1. TAC recommendations for inclusion in index (June 2002).

Recommendation	
1	Vegetation structure (i.e., vertical layer, as well as horizontal distribution) and composition of communities by ecological group (as defined in Fort Benning's INRMP)
2	Soil compaction (may correlate with changes in soil horizon profile)
3	Microfloral populations (applies to both terrestrial and aquatic systems)
4	Plant productivity (applies to both terrestrial and aquatic systems)
5	Soil and sediment carbon
6	Plant (Raunkier) life form for communities
7	Historical land use and current road/trail networks? (both qualitative and quantitative)
8	Remotely-sensed surface cover by ecological group

With these recommendations in hand, the SEMP project manager undertook to interact with the SEMP team leaders and research project principal investigators to determine their thoughts about the most viable measures to use for this purpose. After several iterations, including invitation to add other elements not originally proposed, a larger potential set of 13 index elements was developed. This set is shown in Table 10-2.

Table 10-2. Initial set of potential index elements, including those proposed by team leaders.

Index	
1	Vegetation structure
2	Soil compaction (bulk density
3	Microflora
4	Plant productivity
5	Soil/sediment carbon
6	Raunkier life form
7	Historical land use
8	Surface cover (via RS)
9	A-horizon soil depth
10	Nutrient leakage
11	Ant community structure
12	Species composition
13	Soil/sediment nitrogen

With this set of potential index elements agreed-to, the Team Leaders and Project Manager held a series of conference calls to plan review of the items. A spreadsheet with potential parameters, now 13 in all with the added candidates, was sent to the team leaders, who were asked to rank the parameters on a scale of 1-5, where 1 had a value of "minor potential value," and 5 represented "highly likely to be a good measure." There were seven elements that ranked above 3.75, and appeared to be of the highest value. Initially, these were to be the set used for further analyses.

In practice, and after further discussion among the research teams, it was apparent that modifications would have to be made. There were some elements that resisted quantification. For example, historical land use was unavailable on the scale needed (but see Chapter 3 of this report for a discussion of attempts to ascertain past use). Military use, extremely important to the present needs, was known only as general patterns, and was not site-specific on the scale needed. Vegetation structure and species composition were not immediately quantifiable in simple terms. For at least one parameter, an alternate, but comparable measure was used. Penetrometer readings were substituted for bulk density measures as being a field-measurable value that would also provide information on compaction levels. The set of elements that were agreed-upon by the ranking procedure are shown in Table 10-3.

Table 10-3. Site index elements as ranked.
Elements in bold italics are those in the final set for application.

Element	Score
A-Horizon Soil Depth	***4.8***
Soil/sediment Carbon	***4.6***
Soil Compaction (bulk density)	***4.4***
Vegetation Structure	***4.0***
Species Composition	***4.0***
Historical Land Use	3.8
Soil/Sediment Nitrogen	***3.75***
Plant Productivity	3.6
Surface cover (via RS)	***3.2***
Microflora	2.4
Nutrient Leakage	2.4
Ant Community Structure	2.33
Raunkier Life Form	2.2

In Table 10-3, the elements in bold italics are those in the final set for application. As noted above, there were some deviations from the strict numeric ranking for a variety of reasons. In recognition of the fact that soil nitrogen is usually measured simultaneously in the laboratory with soil carbon, this became a part of the index whose values could be acquired with very minor additional field or laboratory effort. In addition, canopy cover, as measured by densiometer, was added by consensus as a measure that had apparently accidentally been omitted from the list of candidate measures, but was relevant and easily obtained. Most teams reported that they were already acquiring this measure; so, again, there was little added time and cost in acquisition.

Thus, the final set of elements that were to be used to form what was now termed the site condition index consisted of (1) A-Horizon Soil Depth, (2) Soil/sediment Carbon, (3) Soil Compaction, (4) Vegetation Structure, (5) Species Composition, (6) Soil/Sediment Nitrogen, (7) Surface cover (via RS), and (8) Canopy Cover. The next step in the process was the need to test the validity of such an index through one or more successively comprehensive tests.

The first validation test took the form, in early FY03, of assembling data from the several teams that had already acquired the first, and simplest, elements: A horizon depth and soil compaction. Figure 10-2 shows an example of this early aggregation of soil A-horizon depth data from three of the SEMP teams, Florida (CS 1114A – coded JP), Prescott (CS 1114B – coded AJK), and SREL (CS 1114E – coded JJD). In this multiple-element display of data, several hundred samples (306 from Prescott, 384 from SREL, and 130 from Florida) are compared with the previously-ranked (subjective) classification of the site. Overall, among each project's sites, the trend may be seen that the depth of A-horizon decreases greatly, often to zero, as the disturbance class increases. While this is the direction to be expected, the agreement across more than 800 separate samples was gratifying and reassuring.

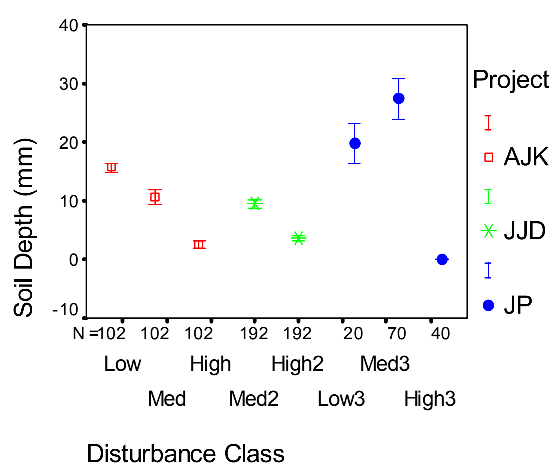

Figure 10-2. A-horizon depth within and between SEMP projects.

What was the next step? Clearly, there were two directions that needed to be pursued. First, data needed to be acquired using more than one or two of the elements in the index. Second, in a separate evaluation it had been determined that the original SEMP sites were not fully representative of the breadth of conditions which existed at Fort Benning. For a variety of reasons, many related to the desire to have study sites that reflected a range of training disturbance gradients, almost all of the scores of existing SEMP sites were in the "middle" range. None had been located in places where training never took place, and none of the permanent sites, where samples were taken over the several years of the project, were located in the areas of greatest military activity. (Likely, because instrumentation, and even site boundaries, would have been totally lost due to the intensive soil disturbance.)

To address both of these issues, in April 2003 the SEMP team led by Dr. Tony Krzysik of Prescott College was charged with two site index tasks, which happened to be very closely related to the needs of their project (CS1114B). First, to select a statistically adequate set of sites that extended the coverage across all soils and vegetation present on Fort Benning. The sites were to represent the widest possible range of landscapes, including ecologically sensitive areas, and to include the most-heavily used military areas. This would correct the previously recognized bias toward "middle" sites. The number agreed to was 40 sites, utilizing, to the greatest degree possible, existing study sites from all the teams. (Twenty-two existing sites were used.) Second, to acquire for each of these sites the "first five" index elements, A-horizon, Compaction, Vegetation (4 elements), Soil C, and Soil N. This was to be performed between May and August of 2003. The tasking was substantially complete by August, and the last few items were acquired in early October. Data analysis took place between that date and December 2003. Some soil nutrient data are still being analyzed in the second quarter of 2004.

Figure 10-3 shows the results of the initial site condition index. This was prepared from the soil A-horizon depth (mm) and soil compaction (Lang units, as measured by the Lang penetrometer). In this graph, the values are ranked from highest to lowest values. Three sites did not have A-horizons. To generate these data, the Prescott-led team took 1600 A-horizon values and 8000 penetrometer readings. This represents 40 A-horizon measurements and 200 penetrometer readings at each of the 40 four-hectare sites. Site means were re-scaled such that the respective sites with the deepest A-horizons or least compacted soils were given a value of 100. All other site values were proportionally scaled. The site index was calculated as the sum of A-horizon and soil compaction divided by two. The maximum possible Site Index value was 100.

Data analysis is continuing, and the remaining elements will be added to the index as they become available. This process is now planned to be substantially complete in mid FY04. It is anticipated that other issues will inevitably arise as to the best manner for comparison of some of the more disparate elements. Among the issues not now fully agreed-upon are the units of measure for vegetation structure and species composition. These may require the formation of like groups within which the quantitative elements may provide the means of comparison. Likewise, there are inherent differences in the natural compaction potential of sandy versus loamy soils, with heavier clay soils still more susceptible. It seems likely that some means must be found to accommodate such differences. Further, when we attempt to rank the “quality” or “naturalness” or level of disturbance or impact, it is important to recognize other inherent differences. The southeastern Sandhills physiography, which is characteristic of much of Fort Benning (and a majority of the SEMP study sites), inherently does not possess very high ground or canopy cover. Many pristine sites may show only 60% canopy cover and 65 to 75% groundcover. This is characteristic of natural xeric sandhills savanna landscapes and inherent ecological processes, not human disturbance.

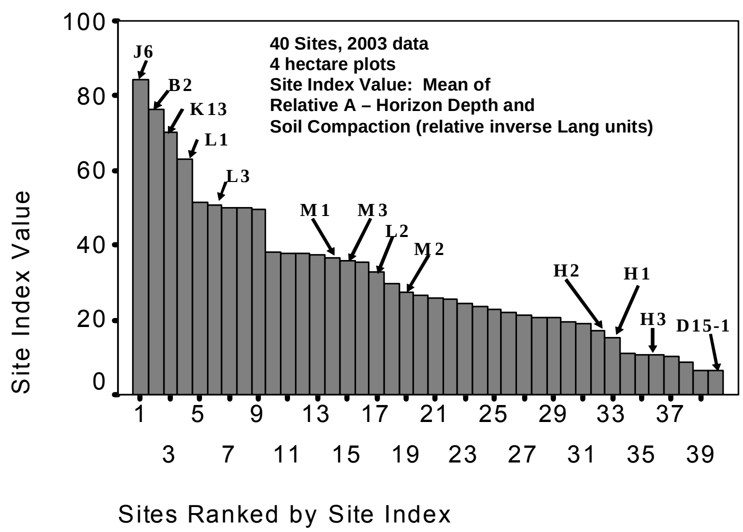

Figure 10-3. Forty sites ranked by initial site index.

There are a variety of concerns that must be addressed. Procedures for data collection will need to be better standardized. More validating tests must be made at other locations on Fort Benning, at other locations within the Sandhills, and elsewhere in habitats that are similar enough that the comparison will be valid. The range of suitability of any particular version of the index will need to be determined, and the need for indices for other habitats must be evaluated. Of further interest is the development of an aquatic/riparian index which goes beyond the focus of present indices for those systems.

Further development of the site comparison index will attempt to incorporate currently identified limitations. The final form may not be a simple numeric rating, which may be what was envisioned originally. Whatever form it eventually takes, the goals will be consonant with the original charge, i.e., develop a way to compare the condition and quality of different sites, both within Fort Benning and elsewhere.

11 Related Research Efforts

Mr. William D. Goran, ERDC/CERL

One of the goals of the SEMP investment was to establish a welcoming and collaborative framework for research at one or more installation locations. Towards this goal, SEMP staff and the host installation(s) have established the following:

- A host-site coordinator, to ensure that all visits by researchers are properly coordinated and safe. The coordination not only provides scheduling services for all research teams that need on-site access to Fort Benning, but also provides access to radios (required for all field teams) and all terrain vehicles.
- A 10-year Memorandum of Agreement (1999-2008) with Fort Benning, to ensure that all coordination issues are well understood by all parties, and to ensure that there is a climate of cooperation and support by all parties engaged in performing or hosting research at Fort Benning.
- A long-term monitoring program, with data on weather conditions, streams and groundwater, and terrestrial and aquatic habitats in selected locations and watersheds across Fort Benning. This data provides a valuable source of "condition" information from 1999 to the present (and, according to plan, through at least a 10-year period), and is supplemented by weather and stream and historic land use and land cover data for decades previous to 1999.
- Primary points of contact at the host site, with clear procedures for interaction and coordination to ensure that these POCs are not overburdened but that they do have knowledge of all research activities and publications resulting from research.
- A repository for research data that provides a framework to ensure that all research data and results are captured in an accessible location that also provides browsing capabilities for any interested party, but controls access to protect intellectual property rights of the researchers.
- Research coordination meetings, regional ecosystem management workshops, and forums at scientific conferences to facilitate exchange between different research groups, installation staff, staff from regional installations, and stakeholders from other State, local, and Federal agencies.
- A technology transition planning process and investment. This process is still being shaped, and SEMP has committed, through both 2003 and 2004 budgets, to coordinated transition planning. Additional plans have matured through meetings and discussions between the SEMP Project Manager, the

Host Site Coordinator, and Fort Benning SEMP POCs, and the installation has provided resources to help develop and resource this effort.

Additional efforts are now underway to "package" these various approaches, and approaches being used elsewhere, such as at Eglin Air Force Base, Florida, and Fort Bragg, North Carolina, to facilitate establishing these research friendly contexts at other installations.

Since the inception of SEMP, dozens of additional research projects have been established at the same host site, or in the Sandhills Fall Line region. The SEMP Host Site coordinator keeps track of those projects that require his services, and includes many projects beyond the monitoring and research efforts within SEMP, in his monthly coordination reports. The host site coordination also plans an annual research coordination meeting every autumn to include interested research teams, numerous installation staff members and contractors, and also local agencies performing research or studies related to understanding ecosystem dynamics.

Some of the research teams that piggyback on SEMP participate in adding data to or using data from the repository, some use the host site coordinator and the vehicles and radios, some participate in the coordination events, and others have helped to host meetings, plan forums, or cooperate in publications and other exchanges. The only "required" coordination is for those teams that work on-site at Fort Benning to schedule their visits through the host site coordinator. Other team involvements are encouraged by SEMP and SERDP, but not required (although SERDP may require specific coordination actions in their annual guidance to related research teams).

11.1 SERDP Sponsored Related Research Projects

- CS-1186: Riparian Ecosystem Management at Military Installations: Determination of Impacts and Restoration and Enhancement Strategies. Principal Investigator: Dr. Pat Mulholland, Oak Ridge National Laboratory. Phone 865-574-7304. Email: mulhollandpj@ornl.gov. Start: 2001. Purpose: To investigate the impacts of military activities (and other activities) on upland and riparian sites, and to evaluate two riparian restoration techniques (e.g., use of woody debris and revegetation). Use of SEMP Resources: Visits scheduled through host site coordinator. Participates in some SEMP TAC meetings and research coordination meetings. Submits data into repository.
- CS-1302: Impacts of Military Training and Land Management on Threatened and Endangered Species in the Southeastern Fall Line/Sandhills Community. Principal Investigator – Dr. Rebecca Sharitz, Savannah River Ecol-

ogy Lab. Phone 803-725-5679. Email: sharitz@srel.edu. Start: 2002. Objective – Evaluate the effects of forest management practices and military activities on threatened and endangered species included in the upland forest communities along the Fall Line Sandhills – to include Fort Benning, Fort Gordon, and Savannah River Site. SEMP Resources include: host site coordinator for visits, submission of data, involvement in research coordination and scientific meetings, and potential submission of topics for Research Integration effort.

- CS-1143: Application of Hyperspectral Techniques to Monitoring and Management of Invasive Weed Infestation. Principal Investigator: Dr. Susan Ustin, University of California, Davis. Phone 530-752-0621. Email: slustin@ucdavis.edu. Project Description: demonstration of identification (mapping) of invasive species via hyperspectral remote imager and GIS technologies. SEMP Linkages: images should be put in repository. Evaluation of outcome for MPRC and other monitoring protocols.
- CS-1100: Predicting the Effects of Ecosystem Fragmentation and Restoration: Management Models for Animal Populations. Principal Investigator: Dr. Thomas Sisk, Northern Arizona State University. Phone 526-523-7183. Email: Thomas.sisk@nau.edu. This project team developed a model that evaluates and predicts the impacts of habitat fragmentation and changes on specific species. Developed for riparian corridors in the western United States, this Effective Area Model (EAM) is being tested, during 2003 and 2004, at Fort Benning and Fort Hood. POC for this testing is Dr. Leslie Ries. Will use host site coordinator for field portion of Fort Benning evaluation. May also participate/nominate topics for Research Integration effort (roads).
- CS-1259: RSim - A Regional Simulation to Explore Impacts of Resource Use and Constraints. Principal Investigator – Dr. Virginia Dale, Oak Ridge National Laboratory. Phone 865-576-8043. Email vhd@ornl.gov. Start: 2002. Objective is to develop a regional simulation environment that integrates environmental effects of on-base training with off-base development. Product is called RSim for Regional Simulation Model.
- CS-1257: The Evolving Urban Community and Military Installations: A Dynamic Spatial Decision Support System for Sustainable Military Communities. Principal Investigators: Dr. Brian Deal, University of Illinois. Phone 217-333-1911. Email bdeal@uiuc.edu. Dr. James D. Westervelt, U.S. Army Corps of Engineers, Engineer Research and Development Center, CERL. Phone 217-373-6785. Email: james.d.westervelt@erdc.usace.army.mil. Start 2002. Project Objective -to develop an understanding of the impacts on military operations from the changes outside the installation, primarily land use changes in the perimeter of military bases. Developing the Land Use Evolution and Assessment Model (LEAM). SEMP Resources: Will contribute to the MPRC monitoring project (e.g., external land use change impact protocol)

and perhaps to the Research Integration effort. No on-site field work. Participant in several resource coordination events.

11.2 Army Sponsored Related Research Projects

Besides these SERDP Projects that are leveraging SEMP, there are numerous other projects, sponsored by Army research, other Defense programs, Fort Benning and some state programs that have been established at Fort Benning (and/or other locations along the Fall Line) that in some manner leverage the resources established for SEMP. Table 11-1 provides summary information about each of these projects - and indicates some of the specific ways in which these projects leverage SEMP resources.

Table 11-1. Summary of related research projects.

Project Title	Primary POC	Sponsor	SEMP Link	Start Year	End year
Gopher Tortoise Study	Dr. Harold Balbach (ERDC/CERL) and Dr. Craig Guyer (Auburn University)	Army RDT&E	A, C	2001	2002
Gopher Tortoise Relocation	Dr. Harold Balbach (ERDC/CERL), Ms. Paula Kahn and Dr. Mary Mendonca (Auburn University)	Army RDT&E & U.S. Fish and Wildlife Service	A, B, C	2003	ongoing
Gopher Tortoise Burrow Collapse	Dr. Harold Balbach (ERDC/CERL), Ms. Paula Kahn and Dr. Mary Mendonca (Auburn University)	Army RDT&E and Ft. Benning	A, B, C	2003	ongoing
Gopher Tortoise Respiratory Tract Disease Study	Dr.Harold Balbach (ERDC/CERL) and Ms. Paula Kahn and Dr. Mary Mendonca (Auburn University)	Army RDT&E and Ft. Benning	A, B	2003	ongoing
Forest Mgmt Effects on Gopher Tortoise	Dr. Harold Balbach (ERDC/CERL) and Ms. Tracey Tuberville, (SREL)	Army RDT&E supplement to SERDP CS-1302	A, D, E	2003	ongoing
Gopher Tortoise Sampling Procedures	Dr. William Meyer (ERDC/CERL) and U. Florida Coop Wildlife Unit	Army RDT&E	A,B, C	2004	ongoing
TES Habitat Fragmentation Study	Mr. Robert Lozar (ERDC/CERL)	Army RDT&E	B, C	2003	ongoing
Urban Impact on	Mr. Paul Loechl	Army RDT&E	B, C	2001	2002

Project Title	Primary POC	Sponsor	SEMP Link	Start Year	End year
Stream Habitat	(ERDC/CERL) and Mr. William Luttersmidt (TRIES, Sam Houston State University)	(Congressional Add)			
Forest Decline and RCW Habitat	Dr. Chris Rewerts (ERDC/CERL) and John Doresky (Fort Benning, GA)	Ft. Benning and Army RDT&E	A, C, D, E	2002	ongoing
Hyperspectral Techniques for Weed Infestations	Dr. Susan Ustin (University of California – Davis)	SERDP (CS-1143)	C, D	2002	
Ecosystem Fragmentation Population Effects	Dr. Thomas Sisk (Northern Arizona University)	SERDP (CS-1100)	C, D	2003 (test of model)	2004
Regional Simulation Model (RSIM)	Dr. Virginia Dale (ORNL)	SERDP (CS-1259)	C,D, E	2002	2005
Evolving Urban Community and Mil. Installations	Dr. Brian Deal (University of Illinois)	SERDP (CS-1257)	C, D, E	2002	2005
Riparian Restoration	Dr. Pat Mulholland (ORNL)	SERDP (CS-1186)	A,B,C, D	2001	2007
Multi-Species of Concern Habitat on Fall Line	Dr. Rebecca Sharitz (SREL)	SERDP (CS-1302)	A, B, C, D, E	2002	2005
Adaptive Grid Modeling of Air Quality	Dr. M. Talat Odman (Georgia Tech)	SERDP (CP-1249)	B,C	2002	2003
Environmental Modeling Linkages	Dr. James Westervelt (ERDC/CERL)	DOD High Performance Computing Office	C,	2004	
Environmental Response and Security Protection	Dr. Rose Kress (ERDC/EL)	Army RDT&E	A,C, D	2003	
Georgia EcoRegions Study	Dr. Jim Gore (Columbus St. Univ)	GA-DNR	A,C	2001	ongoing
Air Quality Impacts from Prescribed Burning	Dr. Karsten Bauman (Georgia Tech)	DOD P2 Partnership	A, B,C	2002	2002
Monitoring Avian Winter Survivorship	Dan Desantes (Institute for Bird Populations)	Legacy Resource Mgmt Program	A,E	2003	2007

SEMP Links:

A) Use of Host Site Coordinator for Scheduling of use of sites on Fort Benning
B) Use of SEMP Repository for data from project
C) Participants in SEMP Research Coordination Meeting
D) Spin-off research effort resulting from SEMP project
E) Outcomes will provide additional data and knowledge relevant to ecosystem management
F) Work done along the Sandhills Fall Line relevant to the Fall Line initiative

12 SEMP Data Repository

Dr. Rose Kress, ERDC Environmental Laboratory, Vicksburg, MS.

12.1 Background

The SEMP data repository was designed to provide data access and exchange among the SEMP study partners and to serve as a stable, long-term data archive platform to protect the SERDP investment. The repository is Internet-based and operates as a simple, functional, stand-alone archive that can be accessed by other more complicated modeling or data systems. It is a file-based repository, organized using a directory structure based on the Spatial Data Standards for Facility, Infrastructure and Environment (SDSFIE) entity set.

12.2 Summary of FY03 Activities

The SEMP Data Repository underwent major redevelopment during FY03. It was redesigned (Figure 12-1) and relocated to the following web address: http://sempdata.wes.army.mil/.

12.2.1 Repository Enhancements

During FY03 there was a major architectural reconfiguration of the SEMP Data Repository. The five main components of that reconfiguration are as follows:

Repository Relocated

The new location of the SEMP Data Repository is at the Engineer Research and Development Center, Information Technology Laboratory (ERDC-ITL) Web Farm. The Web Farm is a collection of servers housed and maintained by ERDC-ITL. For an annual fee, the Web farm maintains the repository and provides any necessary hardware or software upgrades, security checks, and provides routine system maintenance as needed.

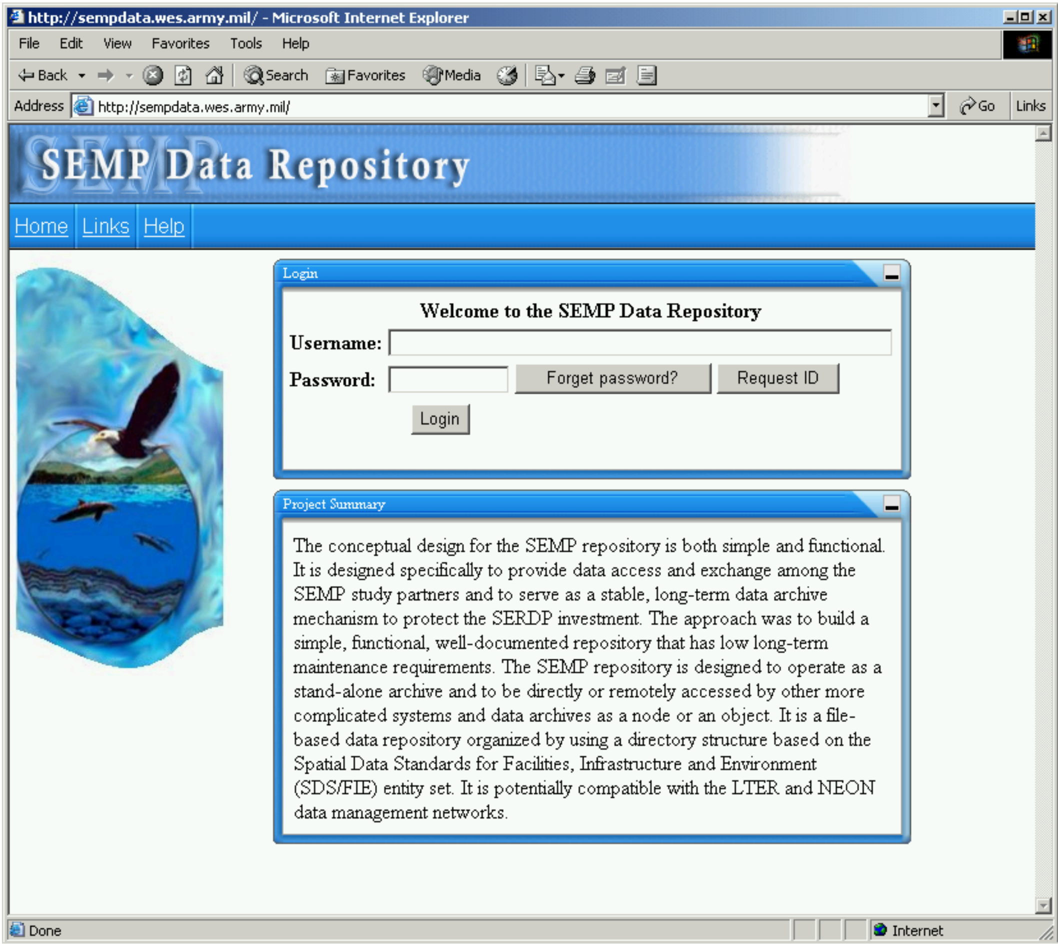

Figure 12-1. SEMP Data Repository home page.

Repository Redesigned

From an architectural standpoint the SEMP Data Repository was reconfigured with the adoption of .net framework technology. This technology required the use of a Windows 2000 (or greater) platform server, running Internet Information System (IIS) web service. The language used to develop the web pages was aspx.net, and the mail tool loaded to handle the repository system e-mails was the Simple Mail Transport Protocol (SMTP).

Repository Transitioned

Transitioning from the old system to the new system called for a completely new design. The design was made to look and feel like an extension of the main SEMP web site. The user interface was modernized and is now portal-like in appearance. The site is database- driven and is running from a MS Access Database. The entire directory structure of the data was altered during the transition. All data files located on the original server were moved, reloaded and relinked in the Access database.

Repository Launched

On April 1, 2003 e-mail was sent to all registered users of the SEMP Data Repository announcing the public launch of the new site. This e-mail requested users to re-register on the new site, update user information, and acquire a new password. All users that were registered and could not be found via their registered e-mail address were expunged from the user database on the new repository.

Repository Modified

1. Password Procedure

The Procedure for awarding users login/passwords has been automated. Upon requesting a User ID the repository automatically sends a password to the e-mail address entered upon registering. The repository is currently open access; all users requesting a password receive one as long as the e-mail address is valid.

2. Data Submissions

The submission procedure allows the users to fill out a simple form by choosing such information as name, file type, keywords, and category, which populates the MS Access database. Once the user submits the data, the repository runs it through a virus check and automatically uploads it to the location selected by the user.

3. Data Search

The options to search for data were limited to the Data Discovery search method that is located on the top of the web pages. First the user selects a major category, the sub-categories available under that category are then shown in the next drop down menu, the user chooses a sub category and the subjects available are then listed in the last drop down menu. If there are no data under a category then you do not see that category as an option. Only available data under available directories are listed in the data discovery search method.

4. Search Results

Results presented to users in an easy to follow format. Data and metadata that are found from the search are indicated by a red check mark next to the title (Figure 12-2).

The card catalog allows users to further explore the information regarding the files before they decide they want to download the data or metadata (Figure 12-3). The Card catalog provides the user information, the file size, file type, and thumbnail (if available) for the data the user searched for.

Title	Data File	Metadata	Card Catalog
Stream Water Chemistry for ORNL1 Study Sites	✓	✓	✓
Stream storm water chemistry data	✓	✓	✓
Water Chemisty Data for Streams North of Fort Benning	✓	✓	✓
Stream Macroinvertebrate Data for ORNL1	✓	✓	✓

Figure 12-2. Data Discover search results on the SEMP Data Repository.

Card Catalog

Title: SREL Penetrometer
Date:
Type: Document/Text
File Format: Tabular (.xls)
File Name: SRELpenetrometer.xls
File Size: 33280
Metadata File Name: SRELpenetrometer.txt

Creator

Member: John Dilustro
Organization: Savannah River Ecology Lab
EMail: dilustro@srel.edu
Phone: (706)545-6136
Fax:
Address: USAIS ATSH-OTR, Bldg 2905
City/State/Zip: Fort Benning/GA/31905

File Format Information

Microsoft Excel Spreadsheet

Related Keywords

soil
Soil Moisture
soil quality
SREL

Figure 12-3. Example of Card Catalog from SEMP Data Repository.

5. Links Page

Links to the SERDP, SEMP, Fort Benning, and all researchers web sites were set up and activated on the SEMP Data Repository Links page (Figure 12-4). The main SEMP site has also set up a link back to the data repository.

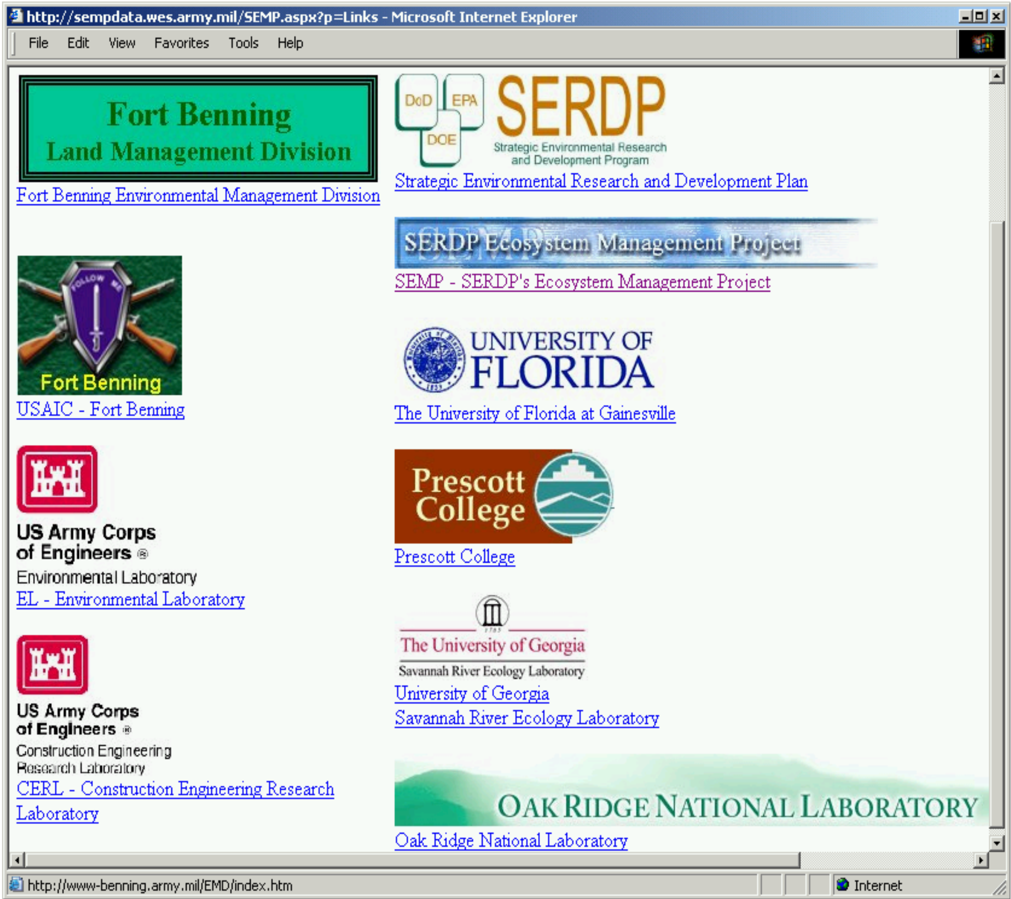

Figure 12-4. SEMP Data Repository links page that was activated in FY03.

6. Request Data Procedure

In order to encourage researchers to share their data with others in the SEMP community, the request data procedure was implemented. This allows users to upload the information about their data; however, the actual data is not submitted. If a user wants more information about the data, the request data button is used. This request sends an e-mail directly to the person responsible for the data, so they can communicate with the person and decide on an individual basis whether or not to provide that data to the person or agency requesting it. This procedure was developed to entice the SEMP Researchers to at minimum submit the information about their data holdings rather than waiting until after they have published before the SEMP community has access to the projects they are conducting.

12.2.2 Repository Use

There were a total of 64 registered users at the end of FY03. Figure 12-5 shows the monthly repository activity for FY03 from April 2003 through September 2003. Activity for October 2002 through March 2003 is unavailable.

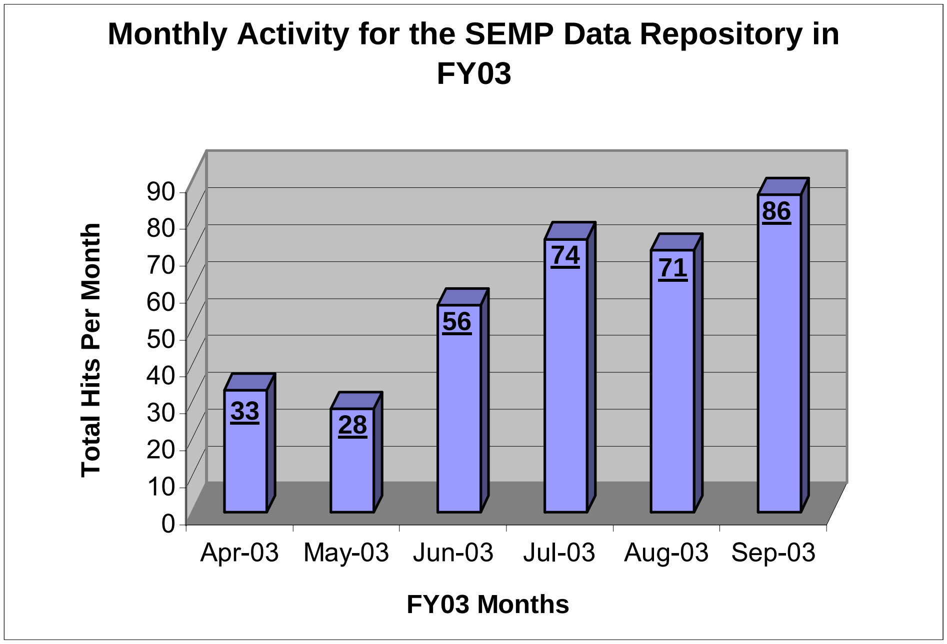

Figure 12-5 Monthly activity on the new SEMP Data Repository in FY03.

12.2.3 Repository Contents

The SEMP data repository contains important baseline geospatial data for Fort Benning and the surrounding region as well as data collected under the monitoring and research efforts underway at Fort Benning. The total volume of data on the site is 1.4 GB. Large Raster files are maintained in a compressed format (.zip) to reduce overall storage requirements and to increast transfer rates. Over a 3-month period 15 MB ofnew data were contributed. These are the only monthly contribution statistics available (Table 12-1). A summary of the entire repository data holdings as of October 1, 2003 is given, by category, in Table 12-2. This table also gives the contributing agency and the number of data sets in the category.

Table 12-1. Volume of data contributed to the Repository by month in FY03.

MONTH	AMOUNT (Megabytes)
July	0.42
August	0.97
September	13.56
Total FY03 Data	**14.95 MB**

Table 12-2. SEMP Repository data holdings for FY03.

Category	Data Holdings	Agency Responsible	#
Boundary	Counties	USAIC-FB / ERDC-EL	1
	Fort Benning Military Installation	USAIC-FB / ERDC-EL	2
	ECMI Management Units	ECMI / ERDC-EL	1
	Military Land Acquisition	CERL	1
Climate	ECMI Weather Station Data Files	ECMI / ERDC-EL	460+
	ECMI Weather Station Summary Sheets	ECMI / ERDC-EL	460+
Ecology	Ecological Units of the Eastern U S	ECMI / ERDC-EL	1
Fauna	LCTA Document 91-95	USAIC-FB / ERDC-EL	1
	Soil Microbial Data	University of Tennessee	1
	Stream Chemistry	ORNL-1 / Auburn Univ.	3
	Stream Chemistry	ERDC-CERL	1
	INRMP Document	USAIC-FB / ERDC-EL	1
Flora	Prescribed Burn Units	USAIC-FB / ERDC-EL	1
	Forest Compartments - old version	USAIC-FB / ERDC-EL	1
	Forest Compartments - revised version	USAIC-FB / LMB	1
	Cover Data	ORNL	1
	Prescribed Burns	USAIC-FB / ERDC-EL	18
	Proposed Burns	USAIC-FB / ERDC-EL	17
	Wildfire Burns	USAIC-FB / ERDC-EL	18
Geology	1:250,000 Geology (Americus Quad)	USAIC-FB / ERDC-EL	1
Hydrography	Lakes	USAIC-FB / ERDC-EL	1
	Streams	USAIC-FB / ERDC-EL	1
	Wetlands	USAIC-FB / ERDC-EL	1
	Watersheds	ECMI / ERDC-EL	6
	USGS HUC Boundary	ECMI / ERDC-EL	1
	Groundwater Wells	ECMI / ERDC-EL	8
	Surface Water Labs	ECMI / ERDC-EL	160
	Water Quality Labs	ECMI / ERDC-EL	6
	Stream Profiles	ECMI / ERDC-EL	6
	Stream Flow	UFLG	10
Imagery	SPOT Image	USAIC-FB / ERDC-EL	1
	DOQ's	USAIC-FB / ERDC-EL	80
	LANDSAT	ECMI / ERDC-EL	3
Land Form	1:24,000 Contour Lines	ECMI / ERDC-EL	1
	1:24,000 Digital Elevation Model GRID	ECMI / ERDC-EL	1
	Erosion & Deposition Data Files.	ECMI / ERDC-EL	70+
Land Status	Historical Witness Tree Data	ORNL	1
	Historical Witness Tree Data Document	ORNL	1
	Historical Land Cover Data	ORNL	1
	LISA Test Location	ORNL	1
	1999 Landcover Classification	ECMI / ERDC-EL	1

Category	Data Holdings	Agency Responsible	#
	2001 Landcover Classification	ECMI / ERDC -EL	1
	NASA MODIS Products	CERL	24
	NASA MODIS Products	ECMI / ERDC-EL	1
Military Operations	Training Compartments	USAIC-FB / ERDC-EL	1
Soils	Soil Layer One	ECMI / ERDC-EL	1
	Soil Layer Two	ECMI / ERDC-EL	1
	Soil Layer Three	ECMI / ERDC-EL	1
	Historical Soil Exclusion Zones	ECMI / ERDC-EL	1
	Surface Soil Texture	ECMI / ERDC-EL	1
	Soil Surface Texture	SREL	3
	Soil Biogeochemical Data	UFLG	2
	Soil Sample Locations	ORNL	5
Transportation	Road Network	USAIC-FB / ERDC-EL	1

13 Host Site Coordinator’s Annual Report

Mr. Hugh Westbury, ERDC/CERL, Fort Benning, GA

At the conclusion of FY03, SEMP had conducted 1700 field trips into the Fort Benning training area without a serious accident and without interfering with military training. In FY03, SEMP researchers conducted a record 563 field trips that required 2320 training compartment reservations and 286 collocation agreements with military training units.

This was the last full year of fieldwork for the original SEMP projects. Joe Prenger, Shirish Bhat, and Noel Cawley have essentially completed the UF soil and hydrology project at Fort Benning. Chuck Garten (ORNL2) has finished the data collection for his soil chemistry study. SREL will collect data on their plots through summer of 2004 in order to measure the effect of the final burn treatment.

The ORNL Kilo Eleven experimental “heavy” disturbance was conducted in May. The effects of this treatment will validate and scale indicators from many SEMP projects. Virginia Dale, Pat Mulholland, Kelly Maloney, and Richard Mitchell collected the initial data for ORNL1 and will continue to monitor the site next year. The Host Site Coordinator provided documentation and graphics for the Fort Benning environmental permit and arranged for the heavy equipment. Tony Krzysik and the CERL team finished up their annual field effort in May. CERL also collected a selected subset of their indicators at study sites used by other SEMP research to support the development of a project-wide disturbance scale and to test their indicators in a wide variety of habitats.

In FY03, additional SERDP-funded projects from SREL and ORNL accounted for about ¼ of the total field effort. The SREL Sandhill/TES Project (CS1302, Rebecca Sharitz PI) commenced fieldwork in 2003. This study will use remote sensing and modeling to identify xeric sandhill areas that would be expected to support rare plant and animal species. Pat Mullholland’ s ORNL3 (CS1186) riparian project completed their second year of fieldwork. They have collected the baseline data and have begun the restoration phase of the project.

New non-SERDP ecological research projects starting at Fort Benning in 2003 investigated the physiological effects of translocation and burrow collapse on the gopher tortoises (GOPHER2, Mary Mendonca PI). These studies are planned to continue in 2004. SEMP also provided field support for Karsten Baumann's Georgia Tech study of the effects of prescribed burning at Fort Benning on the regional air quality.

The Host Site Coordinator provided a presentation at the 2003 Ecological Society of America conference in Savannah, GA. Entitled "Conducting Ecological Studies on a Military Reservation," this presentation described the successes, problems, and solutions from the first 4 years of SERDP-funded research at Fort Benning.

The Host Site Coordinator provides monthly reports on field activity at Fort Benning and maintains an up-to-date GIS layer of all sample sites. These actions enable coordination of field studies between research projects and between the researchers and Fort Benning personnel.

The annual SEMP Research Coordination Meeting was held October 28-30. Thirty-seven representatives from 21 organizations attended the Wednesday Regional Research Coordination Meeting. The presentations were divided into three general topics: Watershed protection, Threatened and Endangered Species, and Environmental Planning Tools. Other meetings of note were the November briefing of the Assistant Deputy UnderSecretary of Defense for Environment, Mr. John Paul Woodley, Jr., at Fort Benning. Mr. Woodley was sufficiently impressed with our project to highlight it in his keynote address at the SERDP-ESTCP annual conference. Brigadier General (Ret) Bob Barnes of The Nature Conservancy was also provided an overview briefing of SEMP. Mr. Barnes, who has responsibility for all TNC-DoD issues, was very interested in SEMP and the concept of ecosystems management.

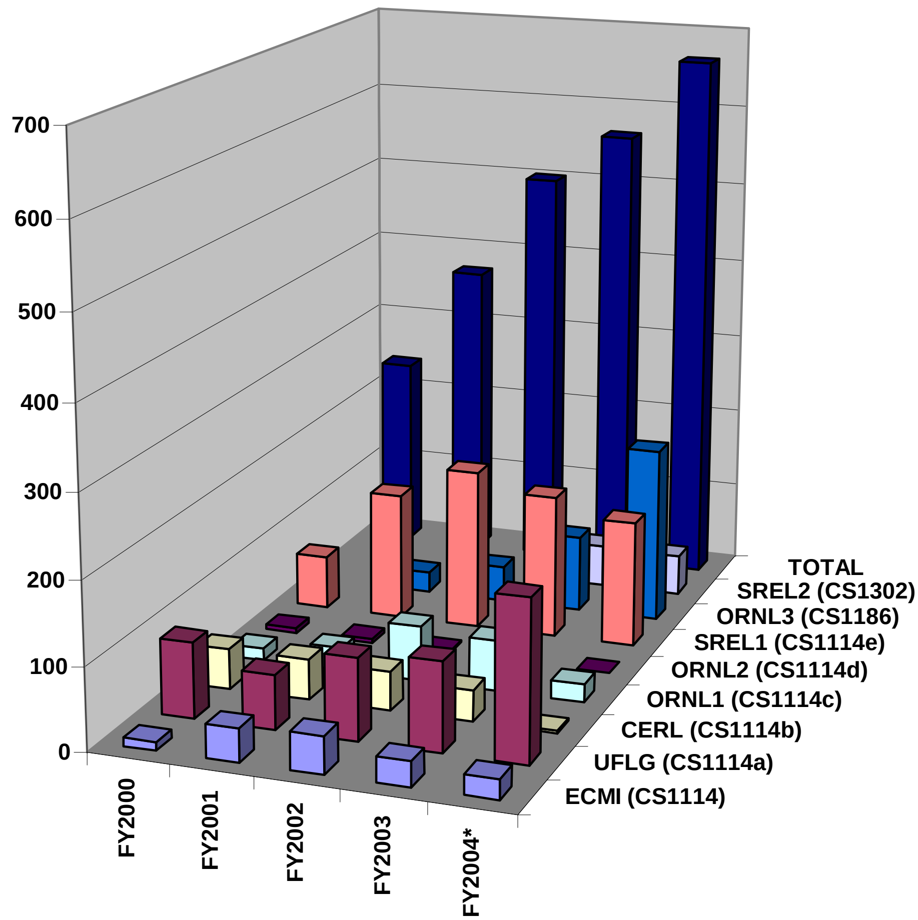

Figure 13-1. SERDP-funded field crew-days at Fort Benning, GA (FY2000-FY2004) by project and total.

FY2004 data is projected.

Table 13-1. SEMP field effort at Fort Benning 2000-2004.

Project Id	FY2000	FY2001	FY2002	FY2003	FY2004*
ECMI (CS1114)	10	40	45	30	24
UFLG (CS1114a)	92	66	99	108	194[A]
CERL (CS1114b)	49	49	47	38	3
ORNL1 (CS1114c)	25	28	67	62	22
ORNL2 (CS1114d)	6	5	2	3	0
SREL1 (CS1114e)	66	157	197	176	155
ORNL3 (CS1186)		25	44	94	216
SREL2 (CS1302)				52	50
TOTAL	248	370	501	563	664
*Projected data – FY2003 projections were 25% above actual [A] Includes 185 days for spring bird survey					

Table 13-2. Actual SEMP field effort FY 2000.
(Number of field crew days.)

Month	ECMI CS1114	UFLG CS1114a	CERL CS1114b	ORNL1 CS1114c	ORNL2 CS1114d	SREL CS1114e	ORNL3 CS1186	SREL2 CS1302	TOTAL
Oct				10					**10**
Nov									
Dec									
Jan	0	6	0	4					**10**
Feb	0	5	0	2	2				**9**
Mar	2	11	2	4	4				**23**
Apr	0	1	0	0	0	5			**6**
May	3	13	26	2	0	5			**49**
Jun	3	29	0	0	0	18			**50**
Jul	1	10	10	0	0	17			**38**
Aug	1	10	10	2	0	15			**38**
Sep	0	7	1	1	0	6			**15**
TOTAL	**10**	**92**	**49**	**25**	**6**	**66**			**248**
Note: Some fieldwork by ECMI and ORNL commenced in October, but there are no records available.									

Table 13-3. Actual SEMP field effort FY 2001.
(Number of field crew days.)

Month	ECMI CS1114	UFLG CS1114a	CERL CS1114b	ORNL1 CS1114c	ORNL2 CS1114d	SREL CS1114e	ORNL3 CS1186	SREL2 CS1302	TOTAL
Oct	0	6	2	1	0	13			**22**
Nov	0	2	10	2	0	10			**24**
Dec	2	5	0	5	0	3			**15**
Jan	2	2	0	5	0	3			**12**
Feb	0	1	0	2	0	8			**11**
Mar	12	7	0	4	0	17	2		**42**
Apr	6	4	12	1	1	15	0		**39**
May	2	3	16	2	4	16	2		**45**
Jun	6	12	9	0	0	20	3		**50**
Jul	3	12	0	0	0	17	13		**45**
Aug	5	10	0	3	0	21	4		**43**
Sep	2	2	0	3	0	14	1		**22**
TOTAL	**40**	**66**	**49**	**28**	**5**	**157**	**25**		**370**

Table 13-4. Actual SEMP field effort FY 2002.
(Number of field crew days.)

Month	ECMI CS1114	UFLG CS1114a	CERL CS1114b	ORNL1 CS1114c	ORNL2 CS1114d	SREL CS1114e	ORNL3 CS1186	SREL2 CS1302	TOTAL
Oct	6	21	0	3	0	17	4		**51**
Nov	0	12	3	7	0	14	0		**36**
Dec	0	5	0	3	0	12	8		**28**
Jan	2	12	0	9	0	14	2		**39**
Feb	0	6	6	3	0	10	5		**30**
Mar	0	9	5	2	0	18	3		**37**
Apr	11	4	5	12	2	20	4		**58**
May	2	4	28	4	0	20	3		**61**
Jun	10	12	0	1	0	18	3		**44**
Jul	10	5	0	10	0	20	4		**49**
Aug	2	3	0	3	0	18	4		**30**
Sep	2	6	0	10	0	16	4		**38**
TOTAL	**45**	**99**	**47**	**67**	**2**	**197**	**44**		**501**

Table 13-5. Actual SEMP field effort FY 2003.
(Number of field crew days.)

Month	ECMI CS1114	UFLG CS1114a	CERL CS1114b	ORNL1 CS1114c	ORNL2 CS1114d	SREL CS1114e	ORNL3 CS1186	SREL2 CS1302	TOTAL
Oct	0	10	4	13	0	15	4	3	**49**
Nov	0	6	0	1	0	11	10	0	**28**
Dec	2	7	0	1	0	11	8	0	**29**
Jan	0	6	0	7	0	13	10	0	**36**
Feb	0	22	0	6	0	13	5	0	**46**
Mar	0	4	0	5	0	10	10	4	**33**
Apr	7	3	9	2	0	17	5	4	**47**
May	10	3	22	6	0	16	6	0	**63**
Jun	0	16	0	4	3	21	11	4	**59**
Jul	6	18	0	6	0	21	10	17	**78**
Aug	0	8	3	2	0	13	7	17	**50**
Sep	5	5	0	9	0	15	8	3	**45**
TOTAL	**30**	**108**	**38**	**62**	**3**	**176**	**94**	**52**	**563**

Table 13-6. Projected SEMP field effort FY 2004.

(Number of field crew days.)
Note: 2003 projection was 25% above actual.

Month	ECMI CS1114	UFLG CS1114a	CERL CS1114b	ORNL1 CS1114c	ORNL2 CS1114d	SREL CS1114e	ORNL3 CS1186	SREL2 CS1302	TOTAL
Oct	2	3	3	1	0	5	18	0	**32**
Nov	2	0	0	1	0	10	14	10	**37**
Dec	2	6	0	1	0	10	9	5	**33**
Jan	2	25	0	1	0	10	17	0	**55**
Feb	2	25	0	1	0	10	18	0	**56**
Mar	2	28	0	0	0	10	25	0	**65**
Apr	2	25	0	0	0	15	35	0	**77**
May	2	25	0	5	0	15	18	0	**65**
Jun	2	27	0	0	0	20	12	5	**66**
Jul	2	20	0	0	0	20	24	20	**86**
Aug	2	10	0	0	0	15	18	20	**65**
Sep	2	0	0	12	0	15	8	5	**42**
TOTAL	**24**	**194**	**3**	**22**	**0**	**155**	**216**	**65**	**679**

14 Technology Infusion and Transfer

PI: Jeff Fehmi
ERDC-CERL, Ecological Processes Branch, Champaign, IL
Associate Investigators:
Teresa Aden and Bruce MacAllister
Army ERDC-CERL, Champaign, IL
30 December 2003

14.1 Summary

The SERDP Ecosystem Management Project (SEMP) nears the successful end of its initial phase – establishing monitoring, and researching indicators and thresholds at Fort Benning. The technology transition plan (this document) [Editor's note: "this document" means "this chapter"] represents the concept and planning document to ensure the SEMP work reaches the critical and maximum audience. There are three main products from SEMP for technology transition: research outcomes, candidate indicators, and lessons learned. Research outcomes include the monitoring protocols, research results, and monitoring trends. Each effort will include their source data in the repository. Recommended indicators represent the subset of research outcomes that monitor key environmental parameters matching the requirements identified by DoD. The lessons learned are the analysis tools for ecosystem trends, information about how to allocate monitoring activities, and how to manage a research program without impacting an installation's training mission.

Technology transition will include four phases: Fort Benning, installations along the Fall Line region, DoD, and beyond DoD. Fort Benning has been the host site for the majority of work to date and will form the template for work elsewhere. Work on the remaining phases will take the forefront after the transition to Fort Benning has been thoroughly worked out. However, the research for the Fall Line phase is already under way through the Fall Line testbed projects and the Fall Line transition has also begun through a symposium. The DoD phase is projected to include all the military services rather than focusing solely on the Army. DoD transition will be made easier due to the regional applicability of much ecological research combined with the other services' installations proximate to the Fall Line. The final phase of the technology transition is to make our monitoring available to some of the national networks and other resource

management agencies. The plan for each phase includes a timeline and identifies those responsible for each main activity.

14.2 Official Milestones

Prepare and present framework for plan	06/2003	Fehmi
Develop SEMP educational materials	12/2003	Aden/MacAllister
Produce tech infusion and transfer plan	12/2003	Fehmi
Coordinate with NEON	06/2004	Fehmi

14.3 Milestone Narratives

14.3.1 Prepare and present framework for plan

Task completed - The framework for the plan was developed and coordinated among the SEMP management team, the Research Integration group, and Fort Benning personnel. This included on-site meetings at each group's respective location. The initial plan framework was presented at the Spring TAC meeting. Basically, the technology transition plan represents the concept and planning document ensuring the SEMP work reaches the critical and maximum audience. There are three main products from SEMP for technology transition: research outcomes, candidate indicators, and lessons learned. Technology transition will include four phases: Fort Benning, installations along the Fall Line region, DoD, and beyond DoD. Fort Benning has been the site for the majority of work to date and will form the template for work elsewhere. Work on the remaining phases will take the forefront after the transition to the host has been thoroughly worked out. This milestone has been successfully completed.

14.3.2 Develop SEMP educational materials

Completion delayed until 3/2004 - An initial draft was produced using Macromedia software. It is an animated/automated presentation with the video tracking a voice over commentary. The video offers the viewer options to hear about different parts of the SEMP effort. It gives the basics of what SEMP is and how it is organized in about 10 – 15 seconds and runs in Internet Explorer. At less than 5 Mb, the file containing the video can be emailed, distributed on CD, or from the SEMP web site. After review by the SEMP management team, the script is being reworked, several graphics changed, and numerous photos added.

14.3.3 Produce tech infusion and transfer plan

Task completed - A plan has been produced. The plan has been reviewed by SEMP management team, the Research Integration group, Fort Benning personnel, and at the Fall TAC meeting. The changes recommended at the Fall TAC meeting are being incorporated and the plan as a whole will be published as an ERDC-CERL Special Report. The largest recommended change to the plan was the addition of each of the individual project's transition plans into the larger plan framework. The report will be sent to the technical editor in January 2004.

14.3.4 Coordinate with NEON

This task was identified during the Fall TAC meeting and has not yet had significant progress.

15 Conclusions

Mr. William D. Goran, ERDC/CERL

15.1 Research

The five indicators and threshold research projects are concluding their field activities, and now aggressively completing and submitting journal publications.

While fieldwork is proceeding as planned, the pace of journal publications submissions still needs to improve. Because publication is such an important outcome for SEMP, and the SERDP Scientific Advisory Board has several times expressed dissatisfaction with previous publication rates for SEMP, the SEMP Technical Advisory Committee recommended that all SEMP performers develop and submit, to the SEMP Project Manager, a detailed publication plan, with month-by-month submission goals for journal articles. Each team has now submitted these plans, and, thus far, research teams have been submitting articles at the rate specified in these plans. The SEMP Project Manager has set a goal, after initial discussions with the SEMP TAC and input from a review of publications from the National Science Foundation, of one journal article per 200K-research investment. At this rate, the SEMP investments to date, 1998 through 2003, should result in about 60 journal articles.

15.2 Monitoring

The monitoring effort now has 5 years (1999-2003) of data, and an effort to analyze the entire record is well underway. While this initial analysis is valuable, efforts in the future need to also focus on examining the relationships between multiple data elements, such as precipitation, ground water levels, surface water levels and biotic responses. These analyses should help us understand nutrient, water, and other cycles, and provide a richer framework for analyses of research data collected in the same timeframe and/or location as monitoring data. During 2002, there were delays with the biological component of the aquatic monitoring, but these have now been resolved, so the Phase I monitoring effort is essentially complete, with a report to be published in 2004 summarizing all the Phase I data to date. Phase II modifications will result from changes to the monitoring plan, such as reductions in data collection intervals, and adaptations to the monitoring plan to accommodate promising indicators and/or specific host installation requirements. Finally, there may be changes to the monitoring plan facilitated by equipment upgrades or replacements; changes in scope (e.g., decisions to monitor additional locations off base), and/or improvements in data sources or types that allow new approaches. There may also be some data elements that transition from the long term monitoring program to an installation monitoring program.

The Research Integration Project made excellent progress during 2003, with all teams actively participating in the nomination of potential indicators, the development of land use and land cover classes, and the assignment of research sites to appropriate classes. A decision was made, during discussions in 2003, to proceed with an additional effort to create a spatially explicit coverage of the entire installation that reflects these land use/land cover designations. Dr. Dale and Mr. Goran gave presentations at the SERDP Symposium in December 2003, summarizing the current approach and status of emerging indicators from SEMP, and the contribution of SEMP to scientific understanding regarding indicators. Installation staff and proponents at these presentations have expressed a strong interest in learning more about these emerging indicators, and implementing the emerging multi-scale protocols, to whatever degree applicable at their locations.

15.3 Handoff

Significant progress was also made on the SEMP technology transfer plan. Dr. Jeff Fehmi worked with all the SEMP performers and focused, this year, on installation handoff issues. The plan, next year, will expand to handoff along the Fall Line. A separate technical report will be published in early 2004, providing extensive details for this technology transfer plan. In addition, Fort Benning has expressed increasing interest in SEMP handoff, and has requested that SEMP put together a proposal to apply relevant technologies and approaches for their planned (construction in 2005) multi-purpose range complex. Mr. Hugh Westbury, the SEMP Host Site Coordinator, will have a first version of this plan in February 2004, with three different plan components (1) products, data, and approaches already completed, relevant to this Digital Multipurpose Range Complex (DMPRC), (2) recommended changes to current SEMP monitoring that can provide additional support to Fort Benning, relative to this MPRC location, and (3) additional efforts recommended for Fort Benning to consider (requiring funds by Benning).

Despite significant progress during 2003, there are many challenges before SEMP, and an external review of this project in 2004 should help provide insight into future management, organization, research directions and collaborations. This review is now being planned, and will be coordinated through the SERDP Program Office.

Appendix A: SEMP Publications

As of March 2004

Summary of Publications

Journal Articles
- Published: 11
- Accepted/In Press: 4
- Submitted: 13

Technical Reports
- Published: 14
- In Press: 1
- Submitted: 2

Theses and Dissertations: 7

CS 1114A – University of Florida and Purdue University – Dr. Reddy

Journal Articles

Accepted/In Press

Bryant, M.L., S. Bhat, and J.M. Jacobs. Spatiotemporal throughfall characterization of heterogeneous forest communities in the southeastern U.S. Journal of Hydrology. (In press)

Submitted

Archer, J., and D.L. Miller. Understory vegetation and soil response to silvicultural activity in a southeastern mixed pine forest: a chronosequence study. Journal of Forest Ecology and Management. (Submitted January 2004)

Bhat, S., J.M. Jacobs, K. Hatfield, and J. Prenger. Ecological indicators in forested watersheds in Fort Benning, GA: relationship between land use and stream water quality. Ecological Indicators. (Submitted February 2004)

Dabral, S., W.D. Graham, and J.P. Prenger. Quantitative analysis of soil nutrient concentrations with near infrared spectroscopy and partial least squares regression. Soil Science Society of America Journal. (Submitted February 2004)

Perkins, D., N. Haws, B.S. Das, and P.S. C. Rao. Soil hydraulic properties as indicators of land quality for upland soils in forested watersheds with military training impacts. Soil Science Society of America Journal. (Submitted December 2003)

Prenger, J.P., W.F. DeBusk, and K.R. Reddy. Influence of military land management on extracellular soil enzymes. Forest Ecology and Management. (Submitted December 2003)

Silveira, M.L., B. Skulnick, W.F. DeBusk, J. Prenger, N.B. Comerford, and K.R. Reddy. In situ and laboratory soil co2 efflux related to military training disturbance in a southern Georgia landscape. Forest Ecology and Management. (Submitted January 2004)

Theses and Dissertations

Archer, J.K. 2003. Understory vegetation and soil response to silvicultural activity in a southeastern mixed pine forest: a chronosequence study. M.S. Thesis. University of Florida.

Chen, Weiwei. 2001. Optimization of terminal restriction fragment length polymorphism and evaluation of microbial community structure as indicator of ecosystem integrity. M.S. Thesis. University of Florida.

Perkins, D. 2003. Soil hydrologic characterization and soil-water storage dynamics in a forested watershed. M.S. Thesis. Purdue University.

Skulnick, B.L. 2002. Soil carbon biogeochemistry: indicators of ecological disturbance. M.S. Thesis. University of Florida.

Tkaczyk, M. 2002. Rainfall runoff and subsurface flow analysis to investigate the flow paths in forested watersheds utilizing TOPMODEL. M.S. Thesis. Civil and Materials Engineering Department, University of Illinois at Chicago.

CS 1114B – Prescott College – Dr. Krzysik

Journal Articles

Published

Duda, J.J., D.C. Freeman, M.L. Brown, J.H. Graham, A.J. Krzysik, J.M. Emlen, J.C. Zak, and D.A. Kovacic. 2003. Estimating disturbance effects from military training using developmental instability and physiological measures of plant stress. Ecological Indicators 3:251-262.

Sobek, E.A., and J.C. Zak. 2003. The soil FungiLog procedure: methods and analytical approaches towards understanding fungal functional diversity. Mycologia 95:590-602.

Accepted/In Press

Freeman, D.C., M.L. Brown, J.J. Duda, J.H. Graham, J.M. Emlen, A.J. Krzysik, H.E. Balbach, D.A. Kovacic, and J.C. Zak. Developmental instability in Rhus copallinum L.: multiple stressors, years, and responses. International Journal of Plant Sciences. (In press)

Freeman, D.C., M.L. Brown, J.J. Duda, J.H. Graham, J.M. Emlen, A.J. Krzysik, H.E. Balbach, D.A. Kovacic, and J.C. Zak. Photosynthesis and fluctuating asymmetry as indicators of plant response to soil disturbance in the Fall Line Sandhills of Georgia: a case study using Rhus copallinum and Ipomoea pandurata. International Journal of Plant Sciences.

Submitted

Emlen, J.M., J.J. Duda, D.C. Freeman, A.J. Krzysik, J.H. Graham, D.A. Kovacic, and J.C. Zak. Complexity of floral community structure as an ecological indicator of ecosystem disturbance and integrity. Applied Vegetation Science. (Submitted January 2004)

Freeman, D.C., M.L. Brown, J.J. Duda, J.H. Graham, J.M. Emlen, A.J. Krzysik, H.E. Balbach, D.A. Kovacic, and J.C. Zak. Leaf fluctuating asymmetry, soil disturbance and plant stress: a multiple year comparison using two herbs, Ipomoea pandurata and Cnidoscolus stimulosus. Ecological Indicators. (Submitted September 2003)

Krzysik, A.J., D.A. Kovacic, M.P. Wallace, J.H. Graham, J.J. Duda, J.C. Zak, D.C. Freeman, H.E. Balbach, and J.M. Emlen. Development of ecological indicator guilds for land management: classifying ecosystem metrics along a landscape disturbance gradient. Ecological Applications. (Submitted September 2003)

CS 1114C – ORNL – Dr. Dale

Journal Articles

Published

Black, B.A., H.T. Foster, and M.D. Abrams. 2002. Combining environmentally dependent and independent analysis of witness tree data in east-central Alabama. Canadian Journal of Forest Research 32:2060-2075.

Dale, V.H., and S.C. Beyeler. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1:3-10.

Dale, V.H., S.C. Beyeler, and B. Jackson. 2002. Understory indicators of anthropogenic disturbance in longleaf pine forests at Fort Benning, Georgia, USA. Ecological Indicators 1(3):155-170.

Dale, V.H., P. Mulholland, L.M. Olsen, J. Feminella, K. Maloney, D.C. White, A. Peacock, and T. Foster. 2004. Selecting a Suite of Ecological Indicators for Resource Management, Landscape Ecology and Wildlife Habitat Evaluation: Critical Information for Ecological Risk Assessment, Land-Use Management Activities and Biodiversity Enhancement Practices. ASTM STP 11813, L.A. Kapustka, H. Gilbraith, M. Luxon, and G.R. Biddinger, Eds. ASTM International, West Conshohocken, PA.

Foster, T., B. Black, and M. Abrams. 2004. A witness tree analysis of the effects of Native Americans on the pre-European settlement forests in east-central Alabama. Human Ecology 32(1):27-47.

Peacock, A.D., S.J. MacNaughton, J.M. Cantu, V.H. Dale, and D.C. White. 2001. Soil microbial biomass and community composition along an anthropogenic disturbance gradient within a longleaf pine habitat. Ecological Indicators 1(2):113-121.

Accepted/In Press

Foster, H.T., II, and M.D. Abrams. Physiographic analysis of the pre-European settlement forests in east-central Alabama. Canadian Journal of Forest Research. (In press)

Submitted

Dale, V.H., D. Druckenbrod, L. Baskaran, M. Aldridge, M. Berry, C. Garten, L. Olsen, R. Efroymson, and R. Washington-Allen. Vehicle impacts on the environment at different spatial scales: observations in west-central Georgia. Journal of Terramechanics. (Submitted January 2004)

Dale, V.H., L.M. Olsen, and H.T. Foster. Landscape patterns as indicators of ecological change at Fort Benning, GA. Land Use and Urban Planning. (Submitted December 2003)

Theses and Dissertations

Beyeler, S.C. 2000. Ecological indicators. Master's Thesis. University of Miami in Ohio.

Foster, H.T., II. 2001. Long term average rate maximization of Creek Indian residential mobility a test of the marginal value theorem. Ph.D. Dissertation. Department of Anthropology, Pennsylvania State University.

CS 1114D – ORNL – Mr. Garten

Journal Articles

Published

Garten, C.T., Jr., T.L. Ashwood, and V.H. Dale. 2003. Effect of military training on indicators of soil quality at Fort Benning, Georgia. Ecological Indicators 3:171-179.

Submitted

Dale, V.H., D. Druckenbrod, L. Baskaran, M. Aldridge, M. Berry, C. Garten, L. Olsen, R. Efroymson, and R. Washington-Allen. Vehicle impacts on the environment at different spatial scales: observations in west-central Georgia. Journal of Terramechanics. (Submitted January 2004)

Technical Reports

Accepted/In Press

Garten, C.T., Jr., and T.L. Ashwood. 2004. Land cover differences in soil carbon and nitrogen at Fort Benning, Georgia. ORNL/TM-2004/14. Oak Ridge National Laboratory, Oak Ridge, TN.

CS 1114E – SREL – Dr. Collins

Journal Articles

Published

Collins, B. 2002. Symposium: regional partnerships for ecosystem research and management. SE Biology 49(4):372-378.

Dilustro, J.J., B.S. Collins, L.K. Duncan, and R.R. Sharitz. 2002. Soil texture, land-use intensity, and vegetation of Fort Benning upland forest sites. J. Torrey Bot. Soc. 129(4):289-297.

Submitted

Dilustro, J.J., B. Collins, and L. Duncan. Ecological thresholds in mixed pine hardwood forests with multiple land use. Applied Vegetation Science. (Submitted December 2003)

Dilustro, J.J., B. Collins, and L. Duncan. Soil nitrogen availability in Fall Line mixed pine forests. Southeastern Naturalist. (Submitted October 2003)

Monitoring Research Program – ERDC/EL – Dr. Price

Technical Reports

Published

Bourne, S.G., and M.R. Graves. 2001. Classification of land-cover types for the Fort Benning ecoregion using Enhanced Thematic Mapper data. ERDC/EL TN-ECMI-01-01. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Graves, M.R. 2001. Watershed boundaries and relationship between stream order and watershed morphology at Fort Benning, Georgia. ERDC/EL TR-01-23. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Graves, M.R., and S.G. Bourne. 2002. Landscape pattern metrics at Fort Benning, Georgia. ERDC/EL TN-ECMI-02-2. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Hahn, C.D. 2002. Evaluation of ECMI instrumentation deployed at Fort Benning. ERDC/EL TN-ECMI-02-1. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Hahn, C.D. 2001. Ground control survey at Fort Benning, Georgia. ERDC/EL TN-ECMI-01-02. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Hahn, C.D., M.R. Graves, and D.L. Price. 2001. S-Tracker survey of sites for long-term erosion/deposition monitoring. ERDC/EL TR-01-18. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Hahn, C.D., and D.L. Leese. 2002. Automated environmental data collection at Fort Benning, Georgia, from May 1999 to July 2001. ERDC TR-02-3. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Kress, M.R. 2001. Long-term monitoring program, Fort Benning, GA; Ecosystem Characterization and Monitoring Initiative, version 2.1. ERDC/EL TR-01-15. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Submitted

Anderson, D., E. Lord, and S. Bourne. SEMP data repository operations. ERDC/EL TR-XX-XX. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS. (Submitted January 2004)

O'Neil, L.J., A. Lee, and D. Price. Terrestrial productivity at Fort Benning, GA; a feasibility analysis: Ecosystem Characterization and Monitoring Initiative. ERDC/EL TN-ECMI-XX-XX. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS. (Submitted January 2004)

Overall SEMP Project – ERDC/CERL – Mr. Goran

Technical Reports

Published

Balbach, H.E., W.D. Goran, T. Aden, D.L. Price, M.R. Kress, W.F. DeBusk, A.J. Krzysik, V.H. Dale, C. Garten, Jr., and B. Collins. 2002. Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Project

(SEMP) FY01 annual report. ERDC SR-02-2. U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, IL.

Balbach, H.E., W.D. Goran, T. Aden, D.L. Price, M.R. Kress, W.F. DeBusk, A.J. Krzysik, V.H. Dale, C. Garten, Jr., and B. Collins. 2001. Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Project (SEMP) FY00 annual report. ERDC SR-01-3. U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, IL.

Goran, W.D., T. Aden, H.E. Balbach, B. Collins, V. Dale, T. Davo, P.J. Guertin, J. Hall, R. Kress, D. Price, and P. Swiderek. 2002. The SEMP approach: plans and progress of the Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Project (SEMP). ERDC SR-02-1. U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, IL.

Lozar, R.C. 2004. SEMP historical meteorology evaluation for the area near Fort Benning, GA: 1999-2001. ERDC/CERL TN 04-01. U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, IL.

Lozar, R.C., and H.E. Balbach. 2002. NASA MODIS products for military land monitoring and management. ERDC/CERL TR-02-31. U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, IL.

Lozar, R.C., H.E. Balbach, W.D. Goran, and B. Collins. 2002. Proceedings of the "Partners Along The Fall Line: Sandhills Ecology and Ecosystem Management Workshop." ERDC/CERL SR-02-2. U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, IL.

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14. ABSTRACT

The SERDP Ecosystem Management Project (SEMP) was initiated in 1998 by the Strategic Environmental Research and Development Program (SERDP), after a 1997 workshop on Department of Defense (DoD) ecosystem management challenges. After the workshop, SERDP allocated initial funding to a new project, titled the SERDP Ecosystem Management Project, designated as CS 1114.

This report provides a comprehensive record of the progress and issues related to SEMP up to and during Fiscal Year 2003 (FY03, October 2002 through September 2003). Chapter 2 provides the status and findings of the monitoring effort, while Chapter 3 describes efforts to obtain comparable climatic and land cover data. Chapters 4 through 8 summarize the projects' status and progress during FY03. This document also presents information on the SEMP integration task, site comparison indices, related research efforts, the SEMP data repository, the host site co-ordinator's report, and technology infusion and transfer.

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